ELECTRICAL
ENGINEERING
JUNE
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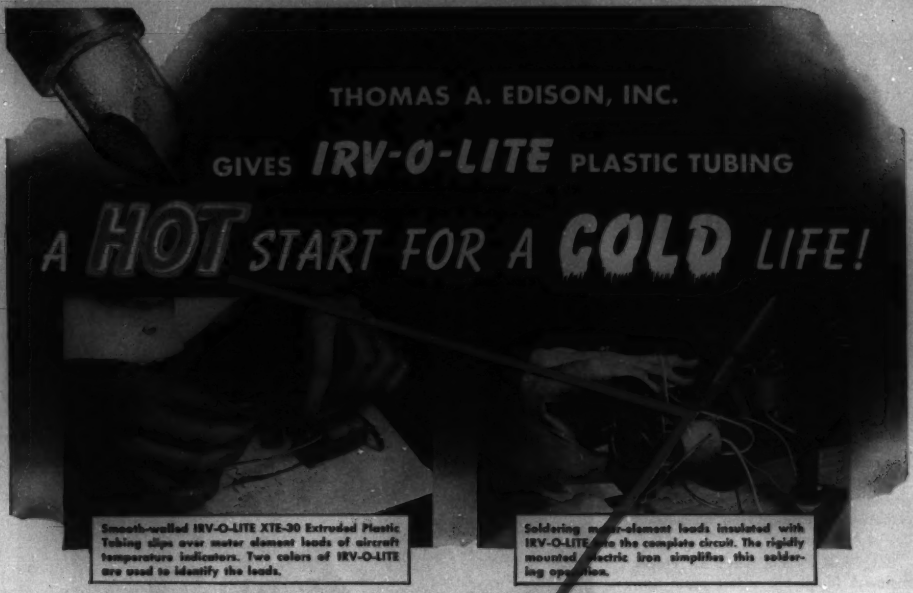
AIEE NATIONAL TECHNICAL MEETING, CLEVELAND, OHIO, JUNE 21-25, 1943



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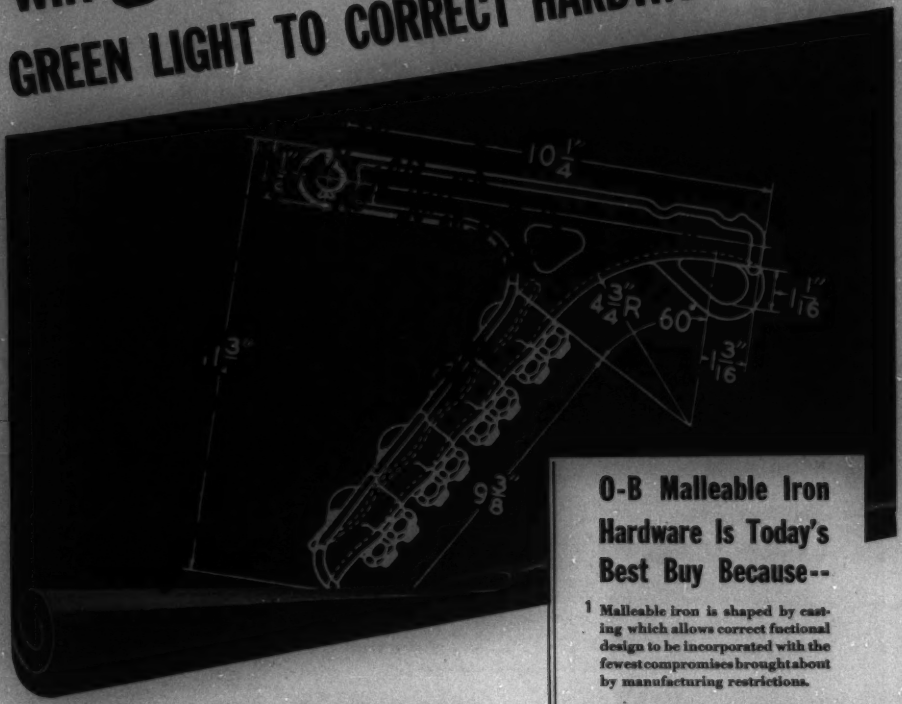

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The Cover: Wartime guides for the application and operation of these and other types of electrical apparatus will be a major topic at the AIEE national technical meeting in Cleveland, Ohio, June 21–25. Headquarters will be at the Hotel Cleveland (*pages 255–8*).

Photos courtesy Westinghouse, General Electric, and Ohio Brass companies, and Lieutenant John C. Beckett, USNR

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The Engineer and the War

H. S. OSBORNE
PRESIDENT AIEE

The engineer's relationship to the war effort and his responsibilities in that effort both as a citizen and as a professional man are subjects of interest to all engineers at the present time.

THE subject of the engineer and the war is an intimate one and associates what are perhaps the two things we are most interested in at the present time; ourselves, the engineers, and the great struggle which is now in full blast to determine the future destinies of the world.

The subject is also a generous one. The highly mechanized character of the war and the tremendous importance in the war effort of production and of engineering and scientific development are such that there can be no question as to the essential relation of the engineer and the war. There is then a wide range of subject matter from which to choose in our discussion of the topic.

One possible approach to the subject of the engineer and the war is to discuss the accomplishments of the engineer in contributing to the war effort. These accomplishments have been very great. It is, of course, necessary that they should be great. Starting practically from nothing, 49,000 military planes were produced in 1942. In 1937 there were 10 shipyards with 46 ways, capable of making ships 400 feet long or over. Now, there are 60 yards with 300 ways, with a total capacity of 20,000,000 dead-weight tons of shipping annually. In the major classes of military needs the production in 1942 runs from 3½ to more than 6 times the 1941 production. The production of 1943 will again be a large step up from that of 1942.

One of the most striking figures is the horsepower of airplane engines required for the planes produced in the United States. Up to the end of 1943, considering only the number of engines necessary to equip the planes, and without allowance for a large percentage of spare engines, this will total 350,000,000 horsepower. This is probably from 1½ to 2 times the total installed central-station power capacity of the world.

These figures speak of accomplishments in which the work of the engineer has been a large and essential part. I speak of them briefly, however, because accomplishments are things done and hence belong to the past. This is a time when I believe we wish to think more about the present and the future.

To some, the consideration of our subject in relation to the present may raise the question of the status of the engineer in the war effort. Is the engineer accorded adequate recognition for his contribution? Does he occupy a position of leadership in the war effort which the importance of engineering in the war would justify? A recent letter received from an engineering group illustrates this point of view. They request that the Institute join them in urging that engineers be delegated to sit at the peace negotiations.

Throughout my professional life I have heard from time to time discussions of the status of the engineer. It seemed to me that this whole question was put in proper perspective by a discussion more than 25 years ago by George F. Swain, in a joint meeting of engineering societies met to consider this topic. Professor Swain said, in effect, that if we believe the engineer has not received proper recognition, let us look to the engineer and his training for the causes for that lack of recognition and the remedies. If the engineer does not lead, said Professor Swain, it must be for the reason that he lacks the personal qualities of leadership, and, if he lacks these qualities, he ought not to lead. The question then comes back to ourselves, to study in what ways, individually and as a group, the engineer's capacity of taking a broader part in the affairs of the world can be increased. If this point of view is accepted, it disposes adequately of this phase of the subject.

If we turn now to the consideration of our subject in relation to the future, I believe it will suggest, at once, to many the responsibilities of the engineer in the war effort.

The war brings increased responsibility to all, as citizens and as workers. This is an inevitable result of times which are crucial in the highest degree—times in which there are many more things to be done and more important things to be done than in any ordinary time. I do not propose to develop this thought further, but mention it, because, while we discuss here particularly our responsibilities as engineers, we must not forget our more general responsibilities as citizens.

When we say that the engineer has a particularly close relation to the war because of the nature of the war effort, we must at the same time recognize that this means also particularly great responsibilities. What are some of these responsibilities?

Obviously, one responsibility of the engineer is to direct his specialized knowledge of engineering to the war effort to maximum advantage. He should be doing

Essential substance of an address presented at the opening session of the AIEE South West District technical meeting, Kansas City, Mo., April 28, 1943.

the kind of work to which he can contribute his utmost. To some this may mean changing from what they are doing to some other work. To most it means continuing on one's present job, but doing it better than he has ever done it before. All this seems to be very elementary in principle, though very complex in individual application.

Many engineers have a responsibility in this matter, not only to themselves as individuals, but to the engineering profession as a whole—a responsibility of helping to insure that engineers be correctly assigned in war work or in the armed forces, and that adequate engineering training be given to young men to insure a continued supply of necessary engineering talent to the armed forces and to industry. I believe that, with the recent developments in Army and Navy training courses, the preferred status of the engineer in the draft, and other recent developments, progress is being made in these matters.

A responsibility of the engineer, closely related to the one we have just discussed, is to keep his mind open and his imagination active to the impact of changing conditions. We all develop, in our work individually and in our organizations, engineering habits. They are great conservators of time and effort and are as necessary to efficient work as the ordinary habits of the individual are to living. We are now, however, in a period of changed and rapidly changing conditions. The engineering habits of yesterday, at least many of them, do not meet the conditions of today. We need to restore in our own minds and in our organizations that habit of questioning every practice, however well-established, which is often the characteristic of a bright young man right out of college. I hope that we will question with more judgment than some of us did when we had just received the coveted diploma. The impact of the scarcity of materials on engineering practices, which is the subject of so much discussion in the Institute meetings this year, is a single illustration of this necessity of questioning and challenging our engineering practices.

In view of the close relation of the engineer to the war effort, he has, I believe, a special responsibility for civilian morale. The engineer is a man "in the know." He may be considered by the nonengineering citizen to be even more "in the know" than he really is. At any rate, his engineering knowledge tends to make him more influential than he may realize in determining the attitude of others toward the uncertainties, the inconveniences, and difficulties, and toward the optimisms and pessimisms which follow each other in rapid succession as the war flows on around us.

Finally, I believe it is the responsibility of the engineer even now to plan ahead. I say even now, because naturally our first responsibility is to give everything we have to advancing the war effort. But we want the war effort and the peace effort which will follow it not only to be effective now, but to continue to be effective throughout the years which will follow. And one essence of engineering is that best results can be obtained only by planning ahead.

Perhaps in speaking of planning ahead, I should first say that we should plan the planning. There is now a tremendous lot of talk going on and a good deal of effort being expended, which relates to the planning of industry for the post war period. The first step is to determine what planning should be done now and what planning should be postponed until a later period.

I am of the opinion that there are no general truths as to when we should start with postwar planning and how fast we should go. I believe, however, that each of us, whether connected with manufacturing, with utilities, with education, or with other aspects of engineering, should seriously consider the subject from the standpoint of his own engineering activities, and determine what are the things which should come first and when those should be done. The postwar world will be full of problems for all of us and it is certainly a necessary part of sound engineering to make forward-looking plans early enough so that they will be ready when needed.

Of course, I have not touched upon all of the major responsibilities of the engineer in these war times. I hope that these illustrations, however, are sufficient to focus in the minds of all of us the point of view that the engineer does have a special relationship to the war effort and, accordingly, has a special responsibility. If we keep this point of view before us as we think of the engineer and the war effort, we cannot go wrong.

Precision-sighting of Garand semiautomatic rifles in quantity production for the United States armed forces can now be done with mirrors and without firing a shot through the use of this optical rifle-sighting gage developed by General Electric Company. The equipment, which was conceived by N. F. Barnes and K. R. Geiser (A '38) of the general engineering laboratory, saves up to 13 rounds of ammunition formerly used in sighting each gun; permits the job to be done in less than two minutes per rifle by one worker, half the time it formerly required two; and takes less room than the average kitchen instead of the 100-yard rifle range needed by the former method

Ultrashort Electromagnetic Waves
IV—Guided Propagation

S. A. SCHELKUNOFF
MEMBER AIEE

When Doctor S. A. Schelkunoff presented the material contained in this article as a lecture before the basic science group of the New York Section, he remarked that it was "nonmathematical." Certainly the electrical engineer will welcome any concept which allows an easier approach to the solution of certain problems involved in wave guides than the more complete equivalent field-theory method. In this fourth article in a series of six on ultrashort electromagnetic waves, Doctor Schelkunoff combines transmission-line theory with optical analogy and derives useful relations for both wave guides and cavity resonators. The three preceding articles appeared in the March, April, and May issues of "Electrical Engineering."

PAUL G. CROMWELL, Chairman, Symposium Committee
(College of Engineering, New York University, New York, N. Y.)

WHATEVER difference there is between the theory and practice of microwaves on the one hand and that of long waves on the other is due to the size of the transmission structures relative to the wave length. Anyone familiar with communication engineering will find the fundamentals of microwave transmission easy to understand, because no new ideas are required; but he should become used to keeping the order of magnitudes in mind and be prepared to find that some conventional types of structures are no longer practicable because of the smallness of their size. The communication engineer's fundamental ideas do not have to be revised, because they are based on the laws of electromagnetic induction which govern the behavior of all electromagnetic waves at high and low frequencies alike. For a review of these laws and their application to transmission lines, the reader is referred to the first two papers in this series.[1,2]

There are two methods of approach to the problem of wave propagation, either along ordinary two-conductor transmission lines or along more general "wave guides" which include single-conductor lines. Both are based on the same fundamental laws of electromagnetic induction and are in a certain sense complementary, each possessing its advantages and disadvantages. One of these methods may be called the "engineering method," because in the past it has been particularly favored by engineers. The other is the "field-theory" method. But these names should not be taken seriously, and we certainly do not wish to imply that the engineers have ignored field considerations. The engineering method is based on the integral equations of induction, although the engineer hides the fact by preferring to express these equations in a verbal form; the second method is based on the differential equations which readily follow from the integral equations. Both methods of solving problems can be exact; but it so happens that it is easier to solve the differential equations in those few instances in which they can be solved exactly, and it is far easier to obtain good approximate solutions of the integral equations when solving the differential equations appears to be a thankless task. The engineer, who is concerned with complicated situations, has picked the best available mathematical method. Consider, for example, a telephone transmission line. For a pair of infinite parallel perfectly conducting straight wires, we can find a simple exact solution of the differential equations. But the actual telephone line is not infinite, is not straight, and is not perfectly conducting; in fact, it is not even a pair of parallel wires but a twisted pair or a transposed pair. Under the circumstances, the problem of solving Maxwell's differential equations is hopeless; but the integral equations, particularly when supplemented by a few measurements, lead at once to a highly satisfactory approximate solution.

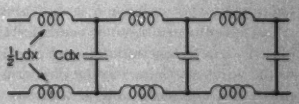


Figure 1. A conventional diagram representing a two-conductor transmission line

I am emphasizing the true nature of the engineering method, because at times it has been said quite unjustifiably that this method is essentially approximate and somehow inferior to the field-theory method.

On the other hand, when the geometry of the transmission system is simple, it is easy to solve the differential equations; the scope of application of these solutions can then be augmented by using them in conjunction with the integral equations.

S. A. Schelkunoff is consultant in electromagnetic theory and member of the technical staff of Bell Telephone Laboratories, Inc., New York, N. Y.

The concepts of resistance, conductance, inductance, and capacitance are very fundamental in that they are based on energy considerations and are quite independent of the frequency. The resistance and conductance are merely the coefficients in the expressions for the electric power transformed into heat; the inductance and capacitance are the coefficients in the expressions for the magnetic and electric energies. When these energies are concentrated in small regions, the precise distribution is unimportant, and integrated values may be used; but generally they are distributed. Hence we have the conceptions of *distributed* resistance, conductance, inductance, and capacitance in "long circuits" or "transmission lines." It is no coincidence that the dimensions of the conductivity, the permeability, and the dielectric constant of a substance are those of conductance per-unit length, inductance per-unit length, and capacitance per-unit length. Through these conceptions of the so-

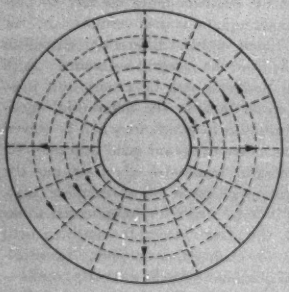


Figure 2. Lines of force in a coaxial transmission line

called "circuit theory," electromagnetic oscillations and waves may be treated as a special case of general Lagrangian dynamics. The ideas of resistance, inductance, and capacitance, simple as they are, belong to advanced dynamics.

TRANSVERSE ELECTROMAGNETIC WAVES

In the case of transmission lines comprised of two independent conductors, it is possible for the nearby sections of these conductors to be oppositely charged and for electric lines to go from one conductor to the other. Magnetic lines surround either one or the other conductor, and we have a wave which is described as a transverse electromagnetic wave, for the reason that the electric and magnetic intensities are both perpendicular to the wires and hence to the direction of wave propagation. The transverse voltage between the wires produces a displacement or capacitance current "in shunt" with the line, and this makes the longitudinal conduction current in the wires vary from point to point. The changing (with time) transverse magnetic field makes the transverse voltage vary from point to point along the line. Thus the voltage and current are propagated along the line, and the nature of this propagation is represented conventionally by the diagram in Figure 1, subject to the interpretation that the series inductance and shunt capacitance are continuously distributed.

The series impedance and shunt admittance per-unit length are respectively

$$Z = R + j\omega L, \qquad Y = R + j\omega C \tag{1}$$

where $\omega = 2\pi f$ is the frequency in radians per second.

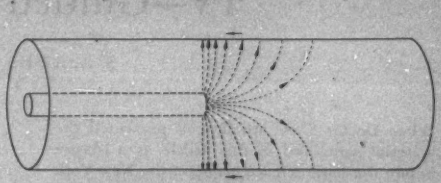


Figure 3. Electric lines of force at low frequencies near the end of the inner conductor of a coaxial pair

For the time being we shall ignore the series resistance due to the conductors and the shunt conductance due to imperfect dielectric between them. In practice these quantities deliberately are kept so small that it is possible to deal with the problem in two steps, that is, to neglect the effect of energy dissipation to begin with, and then to reintroduce it as the first-order correction. The propagation constant is then

$$\Gamma = \sqrt{ZY} = j\omega\sqrt{LC} \tag{2}$$

In a traveling wave, the voltage, current, and field are proportional to $e^{-\Gamma x}$ where x is the distance along the line. Since Γ is imaginary, the absolute value of this exponential factor is unity at all frequencies, and only the phase changes along the line. Of course, energy losses in the resistance will cause a slow attenuation of the amplitude; but this will be dealt with later.

If the dielectric between the conductors is homogeneous, then $LC = \mu\epsilon = 1/v^2$ where v is the velocity characteristic of the medium. In vacuum $v \simeq 3 \times 10^8$ meters per second. Thus we also write

$$\Gamma = \frac{j\omega}{v} = j\frac{2\pi}{\lambda} \tag{3}$$

where λ is the wave length.

The actual values of L and C depend on the field configuration, and those for parallel pairs, for example, are different from those for coaxial pairs. There may also be different *transmission modes* corresponding to different field configurations and hence to different line constants (L, C) consistent with the same physical structure. If a pair of wires is surrounded by a cylindrical shield, symmetric about the pair, there are two obvious transmission modes. In one mode the currents in the wires are equal and similarly directed, and the return current is in the shield; in the other mode the currents in the wires are equal but oppositely directed.

The wave velocity depends only on the product LC; the ratio L/C becomes important when we come to consider the power carried by the wave.

TRANSVERSE MAGNETIC WAVES

We are all familiar with that mode of propagation in a coaxial pair in which electric lines are radial, and magnetic lines are circles (Figure 2). Let us see what happens if we terminate the inner conductor (Figure 3).

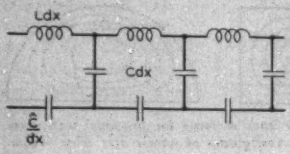


Figure 4. A diagram representing the transmission properties of transverse magnetic waves in wave guides

The electric lines may be expected to bulge out as some charge will be induced on the outer cylinder beyond the end of the inner cylinder. The electric field beyond the terminated end will possess a certain amount of energy and may be represented by a small capacitance $\hat{C}$ between the end of the inner conductor and the outer conductor. At low frequencies the impedance $1/j\omega\hat{C}$ is exceedingly large, and the coaxial pair is practically open in the electrical sense, as well as in the mechanical; but as the frequency increases, this impedance decreases, and the displacement current in the hollow cylinder increases. Now the displacement current, just like the conduction current, is surrounded by magnetic lines; thus with increasing frequency the magnetic field in the hollow cylinder increases, and we are no longer justified in ignoring it. Stronger charging currents will flow in the cylinder, and we begin to realize that the hollow tube is also a kind of transmission line in which the conduction current in the tube returns as the displacement current. The transmission diagram is therefore that shown in Figure 4 in which the series capacitance is included. Those familiar with filters will recognize the structure as a high-pass filter.* At low frequencies

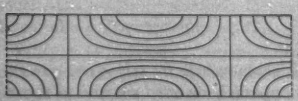


Figure 5. Electric lines of force for the $TM_{0,1}$ wave

the capacitive series impedance dominates the inductive, and the whole structure is capacitive; at high frequencies the inductive reactance dominates, and the structure becomes like the one shown in Figure 1. The effective inductance is diminished by the capacitance, and the wave velocity is increased. The two conditions occur respectively for frequencies less than and greater than the frequency at which the series capacitance resonates the series inductance; at this critical frequency, the series impedance and the propagation constant are reduced to zero.

* It is a band-pass filter when L, $\hat{C}$, C are lumped and a high-pass filter when they are continuously distributed as in the present case.

The series impedance and shunt admittance are

$$Z = j\omega L + \frac{1}{j\omega\hat{C}}, \qquad Y = j\omega C$$

The propagation constant is then

$$\Gamma = \sqrt{\left(j\omega L + \frac{1}{j\omega\hat{C}}\right) j\omega C} = \sqrt{-\omega^2 LC\left(1 - \frac{1}{\omega^2 L\hat{C}}\right)} \tag{5}$$

When ω is small, the quantity under the square root sign is positive, and Γ is real; the field is attenuated at the rate Γ nepers per meter. But when ω is large enough, Γ becomes imaginary, and the field is no longer attenuated. The critical or *cutoff frequency* is given by

$$\Gamma = 0, \quad \omega_c = \frac{1}{\sqrt{L\hat{C}}} \tag{6}$$

Below this frequency the wave is attenuated, even though there is no loss of energy; this means that the energy merely fluctuates between the source (the coaxial pair in Figure 3) and the tube. Above the cutoff some energy passes into the tube and travels along it.

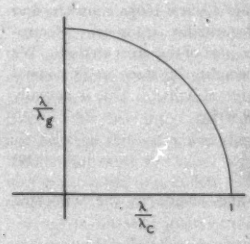


Figure 6. The relationship between the free-space wave length λ, the wave length in the guide λ_g, and the cutoff wave length λ_c

An idea of the order of magnitude of ω_c and the corresponding wave length λ_c may be obtained from the following simple consideration. The series inductance L, representing flux linkages with the longitudinal displacement current, is independent of the area S of the cross section. The series capacitance $\hat{C}$, on the other hand, is proportional to S. Hence ω_c is inversely proportional to $\sqrt{S}$, and λ_c is directly proportional to $\sqrt{S}$ or to the radius of the tube. The exact value of $\hat{C}$ depends on the exact distribution of the longitudinal displacement current. For a rough approximation, assume that the distribution is uniform; then $\hat{C} = \epsilon S$, and† $L = \mu/8\pi$. Substituting in equation 6, we have $\omega_c = 2\sqrt{2}\, v/a$, and $2\pi a = 2\sqrt{2}\,\lambda_c = 2.82\lambda_c$, where a is the radius of the cylinder. A much better approximation may be obtained by assuming a distribution which conforms to the known fact that the longitudinal electric intensity, and therefore the displacement density, must vanish at the conducting boundary. However, for circular tubes the exact value is available, namely $2\pi a = 2.40\lambda_c$.

Introducing ω_c in equation 5 we have

$$\Gamma = j\omega\sqrt{LC}\,\sqrt{1 - \frac{\omega_c^2}{\omega^2}} \tag{7}$$

† The inductance is then the same as for a wire carrying uniform current.

Assuming that $\omega > \omega_c$ we write

$$\Gamma = j\frac{2\pi}{\lambda_g} \tag{8}$$

where λ_g is the wave length in the guide. This length is the span within which the phase takes on all values between 0 and 360 degrees. The wave length λ_g is infinite at the cutoff and then steadily decreases with increasing ω. Every half wave length, the field is reversed and electric lines cannot go on extending as shown in Figure 3; they must assume the form shown in Figure 5 where the distance between successive clusters of lines is $\lambda_g/2$. Magnetic lines are circles linked with electric lines.

The wave velocity in the guide is

$$v_g = f\lambda_g \tag{9}$$

it is infinite at the cutoff and is seen to approach a constant value $1/\sqrt{LC}$ as the frequency increases. But then λ_g becomes small, the electric loops contract, and the field becomes substantially transverse electromagnetic over the greater part of the cross section. We expect the velocity to become the same as in coaxial pairs, that is, the "velocity of light." This is actually the case and we may now write

$$\Gamma = \frac{j\omega}{v}\sqrt{1-\frac{\omega_c^2}{\omega^2}} = j\frac{2\pi}{\lambda}\sqrt{1-\frac{\lambda^2}{\lambda_c^2}} \tag{10}$$

where $\lambda = v/f$ is the wave length in the unlimited medium. The ratio

$$\frac{\lambda}{\lambda_g} = \sqrt{1-\frac{\lambda^2}{\lambda_c^2}} \tag{11}$$

if plotted against λ/λ_c, is represented by an arc of a circle of unit radius (Figure 6).

Below the cutoff Γ is real and

$$\Gamma\lambda_c = 2\pi\sqrt{1-\frac{\lambda_c^2}{\lambda^2}} = 2\pi\sqrt{1-\frac{f^2}{f_c^2}} \tag{12}$$

The plot of $\Gamma\lambda_c/2\pi$ versus λ_c/λ or f/f_c is also a quadrant of a unit circle. Since λ_c is fixed by the dimensions of the tube, the plot represents the variation in Γ.

This wave is no longer completely transverse; only the magnetic intensity is transverse, and for this reason the wave is called a *transverse magnetic* wave.

Suppose now we begin deforming the cross section of the tube. Magnetic lines, unable to penetrate the conductor, will adjust their shape to the new boundary. In tubes of rectangular and semicircular cross section the lines assume the form shown in Figure 7. The field tends to avoid corners; hence we may expect that the effective area of the cross section is smaller than the actual area and that the cutoff wave length is shorter than for a circular tube of the same cross-sectional area.

Imagine a circular tube divided into two halves by a conducting partition along a diameter (Figure 8), and let waves of equal intensity be excited in each half in such a way that magnetic lines are oppositely directed. The conduction currents in the two sides of the partition are also equal and oppositely directed; hence, their effect on the field is canceled, and the partition can be removed without disturbing the field. Thus we obtain

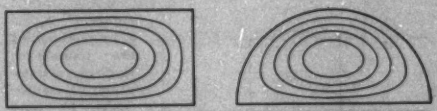


Figure 7. Magnetic lines of force for principal transverse magnetic waves in wave guides of noncircular cross section

another mode of transmission in the circular tube. The cutoff wave length is proportional to the square root of one half of the cross-sectional area and is smaller therefore than for the previous transmission mode. It becomes evident that there will be an infinite number of possible transmission modes. It is particularly easy to enumerate them in tubes of rectangular cross section. Divide the tube into *mn* cells as shown in Figure 9. In each cell establish a wave of the type shown in Figure 7, taking care that the polarities in adjacent cells are opposite. If the intensities of these waves are equal, the partitions may be removed without disturbing the field. This wave is called a $TM_{m,n}$†

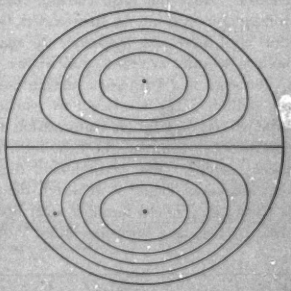


Figure 8. Magnetic lines of force for a $TM_{1,1}$ wave in a circular guide

wave and it may be launched by taking *mn* parallel wires which carry oppositely directed currents as shown diagrammatically in Figure 9, and which are abruptly terminated at some cross section of the tube. The cutoff frequencies evidently increase as *m* and *n* increase. The values of *L*, *C*, *C* depend on the shape and size of the cross section of the tube and on the particular mode.

TRANSVERSE ELECTRIC WAVES

Consider now a transmission line comprised of two parallel wires. Suppose that we insert a conducting loop *ABC* in shunt with the wires as shown in Figure 10. At low frequencies this loop is a practical short circuit, of course; but, as the frequency increases, the impedance

† TM—Transverse magnetic.

of the loop increases, and we have merely a shunt inductance added to the existing shunt capacitance. By placing a succession of such loops along the line, we change the structure from that of Figure 1 to that of Figure 11. A continuous succession of loops on either side of the parallel pair transforms it into a hollow tube (Figures 12 and 13).

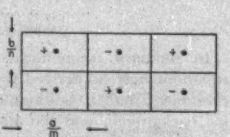


Figure 9. A diagram illustrating the generation of a $TM_{m,n}$ wave in a rectangular guide

At low frequencies the shunt inductive impedance is low, the capacitors are bypassed, and the whole structure is an inductance; but at high frequencies the inductive impedance is high, and the structure becomes similar to that in Figure 1, with the effective capacitance diminished by the parallel inductance. The cutoff frequency which separates these two frequency ranges is that at which the shunt admittance vanishes.

The series impedance and shunt admittance are

$$Z = i\omega L, \qquad Y = i\omega C + \frac{1}{i\omega L} \tag{13}$$

The final form for the propagation constant is the same as for transverse magnetic waves, as given by equation 10. Above the cutoff the wave length in the guide is longer than the free-space wave length to which it is related by equation 11; below the cutoff Γ is real and is given by equation 12.

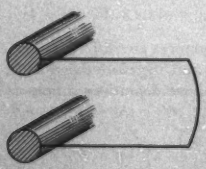


Figure 10. A pair of wires with a conducting loop in shunt with them

Whereas in the case of transverse magnetic waves the conduction current in the tube is longitudinal, in the present case it has also a transverse component. The transverse conduction and displacement currents are naturally 180 degrees out of phase.

The electric intensity is transverse as shown in Figures 14 and 15, but the magnetic intensity has a longitudinal component associated with the transverse current. Magnetic lines form loops (Figure 16) surrounding electric lines. Such waves are called *transverse electric* waves.

In a rectangular tube these waves may be produced by a small doublet antenna placed parallel to the short side. By placing two such antennas energized 180 degrees out of phase we may set up a wave with electric lines as shown in Figure 17. Evidently the cutoff frequency for this wave will be double that of the wave in Figure 14. Similarly we may produce m field reversals. Still another mode of transmission may be generated with four doublets as shown in Figure 18; the arrows on the doublet show the relation between the currents in them at any given instant. If the doublets are not balanced, we may have waves of the preceding types superimposed on that of Figure 18. Out of this field pattern all higher mode patterns are obtained by imagining the guide divided into cells as in Figure 9.

Having enlarged our picture to show the great variety of transmission modes possible in a hollow tube, we must now realize that such modes are possible also in coaxial pairs. These modes have remained unnoticed in conventional practice, because their cutoff frequencies are high, and in low frequency practice they manifested themselves only as "end effects."

FIELD DISTRIBUTION

In order to couple a two-conductor transmission line to a generator, we merely connect their respective terminals. Consequently, we are not particularly interested in the field intensities E and H and are concerned chiefly with their integrated values, the transverse voltage between the wires, and the longitudinal current in them. But there are many ways in which a generator may be coupled to a hollow tube; for example a small antenna or a small loop might be used and might be inserted at different points of the tube. For this reason we become interested in the details of field distribution. Following the line of thought taken in the preceding sections, we can obtain a satisfactory qualitative idea of field distribution, and this method is the only one available when the cross section is not one of the few simple shapes amenable to exact calculation.

It is beyond the scope of this paper to go into details of the general case. For a $TE_{1,0}$ wave† in a rectangular guide the exact field may be calculated as follows: When the magnetic intensity H is eliminated from Maxwell's equations, it is found that each Cartesian component of the electric intensity E must satisfy the wave equation

$$\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial z^2} = -\frac{4\pi^2}{\lambda^2} E \tag{14}$$

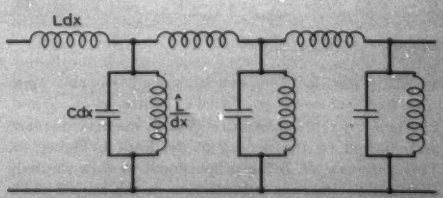


Figure 11. A diagram representing the transmission properties of transverse electric waves in wave guides

† TE—Transverse electric.

In the wave under consideration we have only one component of E. Assuming that the x axis is along the longer side of the rectangle (Figure 14) and the y axis along the shorter, we observe that E_y is independent of the y co-ordinate. Since E_y is also proportional to

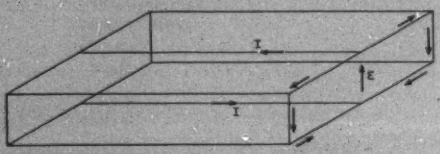


Figure 12. Relative directions of the longitudinal and transverse conduction and displacement currents in a rectangular wave guide for the $TE_{1,0}$ wave

$\epsilon^{-\Gamma z}$, so that its second derivative with respect to z is $\Gamma^2 E_y$, we have from equation 14

$$\frac{\partial^2 E_y}{\partial x^2}+\Gamma^2 E_y=-\frac{4\pi^2}{\lambda^2}E_y$$

or

$$\frac{\partial^2 E_y}{\partial x^2}=-\left(\Gamma^2+\frac{4\pi^2}{\lambda^2}\right)E_y \tag{15}$$

This equation indicates that E_y is a sinusoidal function of x. Since E_y must vanish on the boundaries, $x=0$, and $x=a$, it must be proportional to sin $(m\pi x/a)$ where m is an integer; thus

$$E_y=E_0 \sin\frac{m\pi x}{a}\epsilon^{-\Gamma z} \tag{16}$$

For the $TE_{1,0}$ wave $m=1$.

Substituting from equation 16 in equation 15, we have

$$\frac{m^2\pi^2}{a^2}=-\Gamma^2-\frac{4\pi^2}{\lambda^2}, \quad \Gamma=\sqrt{\frac{m^2\pi^2}{a^2}-\frac{4\pi^2}{\lambda^2}} \tag{17}$$

The cutoff wave length of the $TE_{m,0}$ mode is then

$$\lambda_{m,0}=\frac{2a}{m}, \quad \lambda_{1,0}=2a \tag{18}$$

Knowing E_y we can obtain H_x and H_z from Maxwell's equations; thus

$$H_x=-K_x E_y, \quad H_z=-\frac{m\pi E_0}{i\omega\mu a}\cos\frac{m\pi x}{a}\epsilon^{-\Gamma z} \tag{19}$$

where

$$K_x=\frac{i\omega\mu}{\Gamma} \tag{20}$$

When $m=1$, the maximum E is in the central plane as indicated by the density of the lines in Figure 14. The transverse H, being proportional to E, is similarly distributed; hence it is maximum in the central plane and vanishes at the walls parallel to E. At the surface of each wall this H component determines the longitudinal conduction current; the latter is confined therefore to the walls perpendicular to E and is sinusoidally distributed. The longitudinal H is also sinusoidally distributed except that it vanishes in the central plane; the distribution of the transverse conduction current conforms to this H component. In the walls parallel to E the current is exclusively transverse.

IMPEDANCE

In ordinary communication engineering, the line equations may be derived first in terms of distributed constants L and C; but soon these constants recede into the background, and the attention is centered on the secondary or derived constants, the propagation constant Γ and the characteristic impedance K. The latter may be defined with reference to a progressive wave along the line as the voltage/current ratio (V/I); it may also be defined on the power-current basis or on the power-voltage basis as in the following equations

$$K_{V,I}=\frac{V}{I}, \quad W=\frac{1}{2}K_{W,I}II^*, \quad W=\frac{VV^*}{2K^*_{W,V}} \tag{21}$$

In these equations V is the transverse voltage, I is the total longitudinal current, W is the complex flow of power, and the asterisk indicates conjugate complex numbers so that II^*, for example, is the square of the current amplitude. For transverse electromagnetic waves

$$K_{V,I}=K_{W,I}=K_{W,V}=K \tag{22}$$

but otherwise these three impedances are different.

Above the cutoff W is real, and therefore the K's are real; then we may write the above definitions simply as

$$K_{V,I}=\frac{V}{I}, \quad W=\frac{1}{2}K_{W,I}I^2, \quad W=\frac{V^2}{2K_{W,V}} \tag{23}$$

Evidently we have

$$K_{V,I}=\sqrt{K_{W,I}K_{W,V}} \tag{24}$$

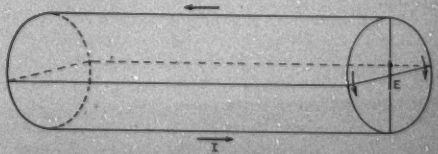


Figure 13. Relative directions of the longitudinal and transverse conduction and displacement currents for the $TE_{1,1}$ wave in a circular wave guide

In wave guides we are also concerned with field intensities, and the most basic of all impedances is defined as the ratio of the transverse field components

$$K_z=\frac{E_t}{H_t} \tag{25}$$

In computing K_z the positive directions of E_t and H_t are so chosen that the real part of K_z is never negative.

The average power carried by the guided wave is obtained by integrating $1/2(E_t \times H_t^*) = 1/2(K_z H_t H_t^*)$ over the cross section of the guide. Thus all integrated impedances are expressible in terms of the wave

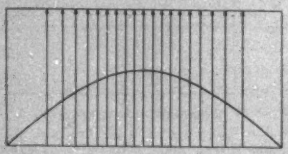


Figure 14. Distribution of transverse electric lines for $TE_{1,0}$ waves

impedance K_z. Above the cutoff for all transverse magnetic waves we have

$$K_z = \sqrt{\frac{\mu}{\epsilon}\left(1-\frac{f_c^2}{f^2}\right)} = 377\sqrt{1-\frac{f_c^2}{f^2}} \tag{26}$$

and for all transverse electric waves

$$K_z = \sqrt{\frac{\mu}{\epsilon}\left(1-\frac{f_c^2}{f^2}\right)^{-1}} = 377\left(1-\frac{f_c^2}{f^2}\right)^{-1/2} \tag{27}$$

The numerical coefficients are for wave guides free from dielectric matter.

For the $TE_{1,0}$ wave in a rectangular guide we find

$$\left.\begin{aligned} K_{V,I} &= \frac{\pi b}{2a} K_z = 592\frac{b}{a}\left(1-\frac{\lambda^2}{4a^2}\right)^{-1/2} \\ K_{W,I} &= \frac{\pi^2 b}{8a} K_z = 465\frac{b}{a}\left(1-\frac{\lambda^2}{4a^2}\right)^{-1/2} \\ K_{W,V} &= \frac{2b}{a} K_z = 754\frac{b}{a}\left(1-\frac{\lambda^2}{4a^2}\right)^{-1/2} \end{aligned}\right\} \tag{28}$$

where a and b are the lengths of the sides respectively perpendicular and parallel to E. The voltage V is the maximum voltage.

For the $TE_{1,1}$ wave in a circular guide we have

$$\left.\begin{aligned} K_{V,I} &= 520\left(1-\frac{\lambda^2}{\lambda_c^2}\right)^{-1/2} \\ K_{W,I} &= 354\left(1-\frac{\lambda^2}{\lambda_c^2}\right)^{-1/2} \\ K_{W,V} &= 764\left(1-\frac{\lambda^2}{\lambda_c^2}\right)^{-1/2} \end{aligned}\right\} \tag{29}$$

For the $TM_{0,1}$ wave† in a circular guide

$$\left.\begin{aligned} K_{V,I} &= 48\sqrt{1-\frac{f_c^2}{f^2}} \\ K_{W,I} &= 30\sqrt{1-\frac{f_c^2}{f^2}} \\ K_{W,V} &= 77\sqrt{1-\frac{f_c^2}{f^2}} \end{aligned}\right\} \tag{30}$$

The voltage V is the transverse voltage from the axis to the boundary.

For the $TM_{1,1}$ wave‡ in a rectangular guide

$$\left.\begin{aligned} K_{V,I} &= \frac{30\pi ab}{a^2+b^2}\sqrt{1-\frac{f_c^2}{f^2}} \\ K_{W,I} &= \frac{15\pi^2 ab}{8(a^2+b^2)}\sqrt{1-\frac{f_c^2}{f^2}} \\ K_{W,V} &= \frac{480ab}{(a^2+b^2)\pi}\sqrt{1-\frac{f_c^2}{f^2}} \end{aligned}\right\} \tag{31}$$

The voltage V is the transverse voltage from the axis of the guide to the boundary; in all the above cases I is the total longitudinal current.

All these impedances are of interest in problems involving gradual changes in the size of the cross section; in order to minimize reflections the characteristic impedance should be kept constant. If the shape of the cross section remains the same, it does not matter which of the integrated impedances is used. When the shape changes, the picture becomes more complicated. Generally speaking, the integrated impedances based on the power flow are more useful than the voltage/current ratio.

Finally, we are particularly interested in the impedance seen by the coupling device, since this impedance governs the transition of power from the device into the wave guide. Such impedances have to be calculated (or measured) for each type of coupling.

ATTENUATION

When an electric current flows through an imperfect conductor, a heating effect takes place, and the energy transformed into heat is abstracted from the energy traveling along the line. In the case of a $TM_{0,1}$ wave in a circular guide, for instance, the resistance R per-unit length of the outer conductor

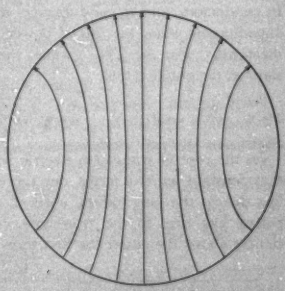


Figure 15. Distribution of electric lines for $TE_{1,1}$ waves

is the same as in a coaxial pair, since the current distribution is the same. The power lost in a length dz of the tube is then $1/2(RI^2)dz$; and if W is the power carried along the guide, then

$$dW = -\frac{1}{2}RI^2 dz \tag{32}$$

† The wave with circular magnetic lines.

‡ Corresponds to the $TM_{0,1}$ wave in a circular guide.

Figure 16. Magnetic lines of force for $TE_{1,0}$ waves in a rectangular wave guide and for $TE_{1,1}$ waves in a circular wave guide

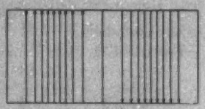


Figure 17. Distribution of electric lines of force for $TE_{1,0}$ waves

Dividing this by W as given in terms of I by equation 23, we have

$$\frac{dW}{W} = -\frac{R}{K_{W,I}}dz \tag{33}$$

where the ratio $R/K_{W,I}$ is independent of z. Hence W is an exponential function of z

$$W = W_0 \exp\left(-\frac{R}{K_{W,I}}z\right) \tag{34}$$

The power is proportional to the square of the current, and therefore

$$I = I_0 e^{-\alpha z}, \quad \alpha = \frac{R}{2K_{W,I}} \tag{35}$$

The exponent α is called the attenuation constant.

In this derivation, we have assumed that the power absorbed by the conductor is a small fraction of that carried by the wave, and that consequently the field distribution and $K_{W,I}$ are not significantly affected. In the immediate vicinity of the cutoff where $K_{W,I}$ is nearly zero, the preceding formula is not good. In this region a formula for α may be obtained by noting that dissipation effects are due to resistances in series with the inductances (in Figures 1, 4, 11) when power is dissipated in conductors, and to conductances in parallel with the capacitances when the loss of power takes place in the dielectric. For the $TM_{0,1}$ wave, the propagation constant at the cutoff is then

$$\Gamma = \sqrt{j\omega RC_{W,I}} = \alpha(1+j), \qquad \alpha = \sqrt{\frac{1}{2}\omega RC_{W,I}} \tag{36}$$

In the case of transverse electric waves, the attenuation constant has two terms, one representing the power loss due to the longitudinal current, and the other the power loss due to the transverse component. Sufficiently above the cutoff the first term is proportional to $\sqrt{f}$ and the second to $f^{-1/2}$ as may be seen from equation 13.

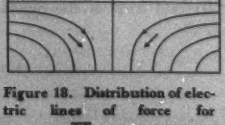


Figure 18. Distribution of electric lines of force for $TE_{1,1}$ waves

The attenuation is high close to the cutoff, because very little power is carried by the wave; as the frequency increases, the attenuation first decreases because of the increased power carried by the wave; then the latter reaches a constant value, and the attenuation becomes proportional to the surface resistance of the conductor and therefore increases as $\sqrt{f}$.

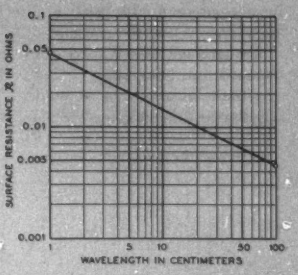


Figure 19. Surface resistance of copper conductors as a function of the wave length

Generally $\Re = \sqrt{\pi\mu f/g}$ *ohms where* f *is the frequency,* μ *the permeability in henrys per meter, and* g *the conductivity in mhos per meter*

The attenuation may be expressed conveniently in terms of the resistance $\Re$ of a unit area of the conductor (Figure 19). Thus for transverse magnetic waves in a circular tube we have

$$\alpha = \frac{\Re}{a\sqrt{\frac{\mu}{\epsilon}}}\left(1-\frac{f_c^2}{f^2}\right)^{-1/2} = \frac{\Re}{377a}\left(1-\frac{f_c^2}{f^2}\right)^{-1/2} \text{ nepers per-unit length} \tag{37}$$

For a $TE_{1,1}$ wave in a circular tube we have

$$\alpha = \frac{\Re}{a}\left[3.76\left(1-\frac{f_c^2}{f^2}\right)^{-1/2} - 2.65\left(1-\frac{f_c^2}{f^2}\right)^{1/2}\right]10^{-2} \tag{38}$$

and for a $TE_{1,0}$ wave in a rectangular tube we have

$$\alpha = \frac{\Re}{377}\left(\frac{1}{b}+\frac{2f_c^2}{af^2}\right)\left(1-\frac{f_c^2}{f^2}\right)^{-1/2} \tag{39}$$

For a more complete list of attenuation formulas, see reference 4.

The attenuation constant does not actually become either infinite or even large at f_c. Thus for the $TM_{0,1}$ wave in an empty circular tube at that frequency for which the series reactance per-unit length vanishes, $\alpha = \sqrt{\Re/60a\lambda}$. This frequency is $f_1 = f_c(1-\Re a/346\lambda_c)$, where f_c is the cutoff frequency when $\Re = 0$. For frequencies lower than f_1, the attenuation is practically independent of $\Re$ and is given by equation 12. There is only a very narrow frequency range in the vicinity of f_1 and f_c where neither equation 12 nor equation 37 is applicable; the point corresponding to f_1 may thus be used for joining the two attenuation curves.

REACTORS IN WAVE GUIDES

When a capacitor or an inductor is placed in shunt with an ordinary transmission line, it causes a local storage of energy. Part of the energy traveling along the line is withdrawn from it during one half of the cycle and returned during the other. In effect we have a virtual generator† which sends waves in both direc-

† A generator which on the average contributes no power.

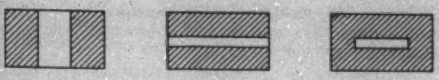


Figure 20. Irises in rectangular wave guides

tions; the wave traveling back to the actual generator is called the reflected wave. More generally a reflection takes place at any impedance discontinuity.

Similar conditions exist at impedance discontinuities in hollow tubes. Consider, for example, a rectangular guide, and introduce a metal partition to block partially the passage of the wave. If the frequency is between the lowest cutoff frequency and the next higher, the energy is transmitted over large distances in only one mode ($TE_{1,0}$). The current in the partition will produce other modes as well, but these are attenuated with the distance from the partition and thus will represent a local storage of energy. When the edges of the partition are parallel to the electric vector, as in the arrangement shown in Figure 20A, the current may flow freely from top to bottom, the local field is largely magnetic, and the partition behaves as an inductance. In the arrangement shown in Figure 20B, charges are accumulated on the upper and lower parts of the partition, the local field is largely electric, and we have a capacitor. In the arrangement shown in Figure 20C the reactance may be either inductive or capacitive, depending on the relative dimensions of the slit. The shunt inductance may actually resonate the shunt capacitance, thus making the shunt impedance infinite at some particular frequency; then the partition will not be seen by the wave which will pass through the slit without reflection.

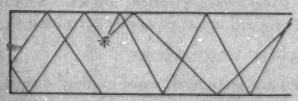


Figure 21. A source of light inside a metal tube

Figure 22. An antenna inside a metal tube

The conditions become different when the frequency exceeds the second cutoff frequency. Whatever fraction of the energy passing the partition happens to be taken from the first mode and transformed into the second is lost to the first mode. The partition will then act not only as a reactive discontinuity, but also as a positive resistance to the original incident wave and a negative resistance to the second mode. A similar situation exists if an antenna is inserted in shunt with a parallel-wire transmission line; the radiated energy is lost as far as the plane wave guided by the wires is concerned, and at the same time we have a source of the energy carried by the spherical wave emitted from the antenna.

OPTICAL ANALOGIES

In the foregoing discussion of wave guides the transmission-line aspect has been emphasized for a perfectly obvious reason: the wave guides are of practical interest, because they are transmission systems. In the initial stages, however, when we are trying to become familiar with an unfamiliar phenomenon, any connection with something we think we know well is very helpful. Even the most elementary books in physics discuss light waves and uniform plane waves, and most everyone knows that antennas radiate energy which may be picked up somewhere else. We shall now look at wave guides from a point of view which is particularly congenial to the physicist and acceptable to the radio engineer, but alien to the wire-communication engineer, and at best is quite limited when one wants to make a full use of wave guides as transmission systems.

Imagine a source of light inside a metal tube. Waves are emitted in all directions and are reflected in some such fashion as that indicated in Figure 21. The emitted energy will be directed† along the tube, although the walls of the tube will absorb some of it. Thus some electromagnetic waves can be transmitted through a hollow tube. But is the transmission possible at "engineering frequencies" which are so much lower than light frequencies? Let us think then of an antenna radiating between the surface of the earth and the Kennelly-Heaviside layer. There we think of sky waves bouncing back and forth between the layer and the earth in a way similar to that in Figure 21. We now take the ground, improve it by making it of copper, and wrap it around the antenna to form a tube, Figure 22. We know that if the antenna is short compared with the wave length, very little energy is radiated for a given current in the antenna. The antenna must approach a quarter wave length before a substantial amount of energy is radiated, and we conclude that the diameter of the tube should not be much less than $\lambda/4$. This picture, however, does not give us a precise idea with regard to the critical frequency; in fact, it gives us no indication that, if the diameter is smaller than 0.6λ, *the antenna will not radiate*.

There are other differences between light waves and guided waves. In the case of the former, we think of the tube merely as a boundary keeping light from escaping the tube; our attention is concentrated on the medium inside the tube. If there is a narrow slit in the tube, some light escapes; but we feel that the orientation of the slit is not important. On the other hand in the wave guide (Figure 12), the orientation of the slit is very important. A longitudinal slit in the middle of

† The word "directed" is now perhaps a better description of what happens than the term "guided."

the broad top face will interfere with the flow of current but slightly, and its effect on the wave will be small; but a longitudinal slit in either of the side faces will interrupt the transverse current and produce a considerable effect. As the frequency increases, this effect becomes smaller, because the transverse current becomes smaller. Transverse slits will act in just the opposite way: the effect is small for slits in side faces and large for slits in the other two faces. A light wave would always be reflected from a transverse partition (Figure 20), but we saw that a $TE_{1,0}$ wave could pass through a narrow window. Light energy seems to be radiated equally well whether the tube is twice as large or twice as small—impedance considerations are nowhere in sight; but these considerations are of paramount importance in the construction of high-quality transmission systems.

The optical theory breaks down for this reason: Light waves are of such high frequency that they are above the cutoff for a very large number of transmission modes, and hence the energy is propagated in all these modes; but wave guides are operated at frequencies at which

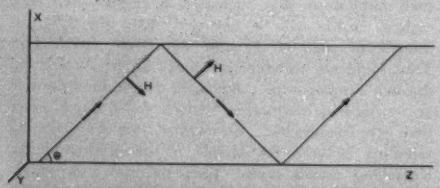


Figure 23. Illustrating a uniform plane wave reflected back and forth between two perfectly conducting planes

only one mode or at most a few modes partake in transmission of energy.

We shall not consider the relationship between guided waves and the uniform plane waves on which the wave theory of light is based. Imagine two parallel metal planes whose cross section is shown in Figure 23 and an ordinary plane wave, with E parallel to the metal boundaries. At each boundary this wave is reflected in such a way that the total E vanishes. This means that the electric intensities of the incident and reflected waves are equal and opposite. Thus at the origin the electric intensity will be of the following form

$$E_y = E_0 \exp\left[-\frac{2\pi j}{\lambda}(x \sin\theta + z\cos\theta)\right] - E_0 \exp\left[-\frac{2\pi j}{\lambda}(-x\sin\theta + z\cos\theta)\right] \quad (40)$$

$$= -2jE_0 \sin\left(\frac{2\pi}{\lambda} x \sin\theta\right) \exp\left(-j\frac{2\pi}{\lambda} z\cos\theta\right)$$

When $x = a$, E_y must also vanish; therefore

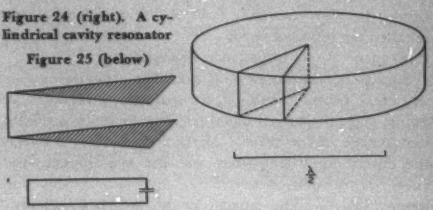
$$\frac{2\pi a}{\lambda}\sin\theta = m\pi, \quad m = 1, 2, 3, \ldots \quad (41)$$

$$\sin\theta = \frac{m\lambda}{2a}$$

If this value of sin θ is inserted in equation 40, we obtain equation 16.

Figure 24 (right). A cylindrical cavity resonator

Figure 25 (below)



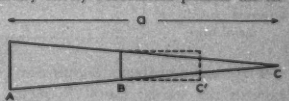
A $TE_{m,0}$ wave may be regarded therefore as a zigzagging uniform plane wave. We have connected a less familiar type of wave with a more familiar one, and we are apt to feel that we now understand the former better, that is, if we do not press the matter too far. Equation 41, for instance, says that a plane wave is "permitted" to zigzag only at specified angles, depending on the wave length; that if $\lambda = 1.5a$, there is only one permitted angle; and that if $\lambda = 3a$, so that sin $\theta > 1$, there are no permitted waves at all. Of course, if we ignore the physical significance of equation 41 and eliminate sin θ from equation 40, things are set right; then, however, we lose the individual plane waves with which we started.

Such embarrassing questions do not arise in the case of light waves whose wave lengths are of the order of 2.27×10^{-5} inches so that if $a = 1$ foot, let us say, there would be about 1,000,000 permitted angles. Small random variations in a will make all angles permitted.

CAVITY RESONATORS

Cavity resonators are sections of wave guides,† closed at both ends to form metal boxes in order to prevent energy escaping to free space. In this sense they behave as sections of transmission lines, short-circuited at both ends. Like the latter, cavity resonators possess an in-

Figure 26



finite number of resonant frequencies. To each transmission mode there will correspond a set of oscillation modes, corresponding to an integral number of half wave lengths (the guide wave lengths) along the guide; but some of these oscillation modes will be duplicated.

A pillbox (Figure 24) is a simple cavity resonator. It may be regarded either as a section of a cylindrical guide

† Of either uniform or nonuniform cross section.

or as a section of a "disk transmission line" formed by two parallel planes. In the latter case we may start with a source on the axis and think of a cylindrical wave spreading outward. Consider a particular wave in which the E lines run from one plane to the other. This wave will be reflected back toward the axis and interfere with the original wave to form a standing wave. Our first idea may be that at resonance the radius will be equal to $\lambda/4$; but then we shall recall that this result is obtained for transmission lines with uniformly distributed capacitance and inductance, whereas for the cylindrical wave under consideration the capacitance per-unit radius increases with the distance from the axis. This is particularly evident if we cut a thin "pie" out of the "cake," Figure 24. We now have a pair of wires open at one end and short-circuited at the other. In considering waves in this pair of wires we should think of electric lines going straight between the triangular conductors, since this is what happens in the box on account of the proximity of the adjacent wedge-shaped sections. The nonuniformity of the capacitance distribution should alter the effective length of the transmission line. If we have an excess of capacitance near the open end (Figure 25), the section of the line is made effectively longer, and the resonant wave length will be greater than four times the actual length of the section. The capacitance deficiency near the short-circuited end does not have much effect, because the voltage is small there. Returning to our section of the pillbox, we find the capacitance deficiency at the open end which makes the line effectively shorter. The resonant wave length will then be less than four times the actual length of the section. Pursuing the matter further, we should say that (Figure 26) when $BC=a/\sqrt{2}=0.707a$ and $AB=0.293a$, the capacitance is evenly divided. Of course, in estimating the effect of uneven capacitance distribution on the resonant wave length, we should give due weight to the voltage distribution. Since, however, the voltage varies slowly near the open end, we shall ignore this variation. Thus we shall replace the triangular piece of length $BC=0.707a$ by a rectangular piece of the same area and hence of length $BC'=0.354a$. The effective length of our nonuniform line becomes then $AC'=0.646a$, and the resonant wave length $\lambda=4AC'=2.59a$. The exact value to two decimal figures is $\lambda=2.62a$. Our result is almost as good as we can get from the formula

$$\lambda=4a\sqrt{\frac{1+\xi}{1-\xi}},\qquad \xi=\frac{\int_0^a C\cos\frac{\pi x}{a}\,dx}{\int_0^a C\,dx} \tag{42}$$

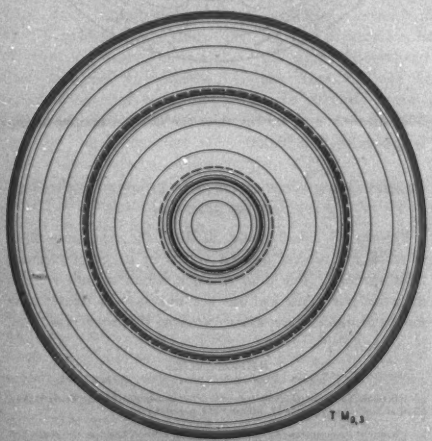
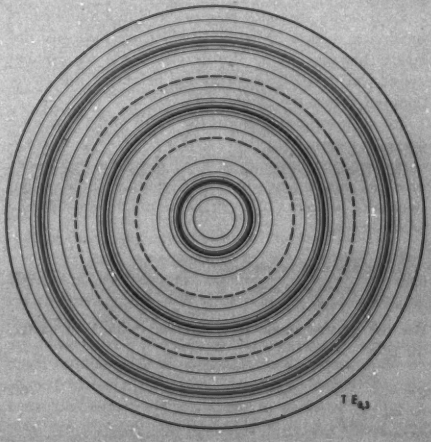


Figure 27. Circular magnetic waves ($TM_{0,M}$) in metal pipes of circular cross section

The solid lines are magnetic lines of force. The projections of electric lines of force on a transverse cross section are perpendicular to the magnetic lines. The boundary and the dotted circles are lines of zero electric potential, and, therefore, perfectly conducting cylindrical partitions, coaxial with the pipe and passing through the dotted circles, can be inserted without disturbing the field. The number of such partitions is M. The radii of the nodal circles are approximately proportional to 2.40, 5.52, 8.65, 11.79, 14.93, 18.07, . . ., K_m, $K_m+\pi$, . . .

Figure 28. Circular electric waves ($TE_{0,M}$) in metal pipes of circular cross section

The solid lines are electric lines of force. The projections of the magnetic lines of force on a transverse cross section are perpendicular to the electric lines. The boundary and the dotted circles are lines of zero electric field, and, therefore, perfectly conducting cylindrical partitions, coaxial with the pipe and passing through the dotted circles, can be inserted without disturbing the field. The number of such partitions (including the boundary of the guide) is M. The radii of the nodal circles are approximately proportional to 3.83, 7.02, 10.17, 13.32, 16.47, 19.62, 22.76, 25.90, . . ., K_m, $K_m+\pi$, . .



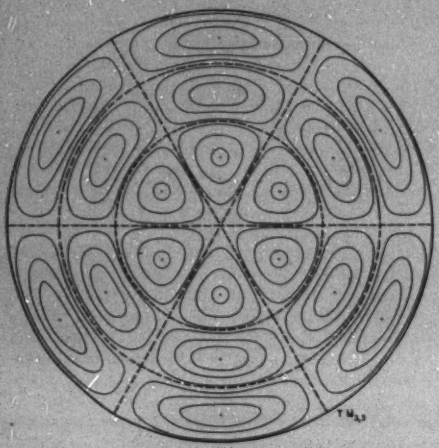


Figure 29. Transverse magnetic sectorial waves ($TM_{L,M}$)

The solid lines are magnetic lines of force. The projections of electric lines of force on a transverse cross section are perpendicular to the magnetic lines. The boundary and the dotted lines are lines of zero electric potential, and, therefore, perfectly conducting cylindrical partitions passing through these lines whose generators are parallel to the axis of the pipe, can be inserted without disturbing the field. Among the above nodal lines there are L diameters and M circles

in which the effect of the voltage variation along the line is taken into consideration by assuming that the distribution is sinusoidal (as would be the case if the line were uniform). In the preceding formula x is measured from the open end, and in the present case C is proportional to x.

Each cavity resonator possesses an infinite number of oscillation modes. The mode which we have just discussed happens to be the gravest mode for circular cylindrical cavities, provided the height of the cavity does not exceed the diameter $2a$.

For each oscillation mode, the width of the resonance curves is measured by the ratio $Q = f_0/(f_2 - f_1)$, where f_0 is the resonant frequency and f_1, f_2 are the frequencies on either side of f_0 at which the amplitude of the oscillations is 71 per cent $(100/\sqrt{2})$ of the maximum. It may be shown that

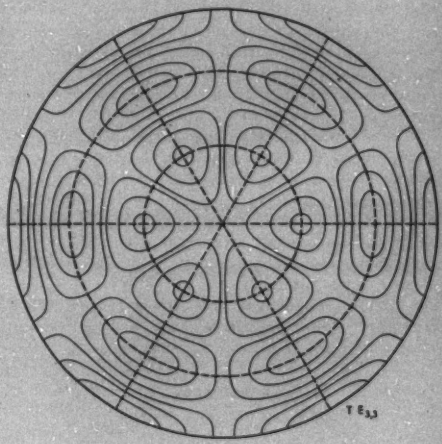
$$Q = \frac{\omega \times \text{energy stored at resonance}}{\text{power dissipated}} \qquad (43)$$

For the gravest mode in a circular cylindrical cavity, the Q is

$$Q = \frac{452}{\Re\left(1+\frac{a}{h}\right)}, \qquad h \leq 2a \qquad (44)$$

Figure 30. Transverse electric sectorial waves ($TE_{L,M}$)

The solid lines are electric lines of force. The projections of magnetic lines of force on a transverse cross section are perpendicular to the electric lines. The component of the electric force tangential to the boundary and to the dotted lines is zero, and, therefore, perfectly conducting cylindrical partitions passing through these lines whose generators are parallel to the axis of the pipe, can be inserted without disturbing the field. Among the above nodal curves there are L diameters and M circles



Thus if $a = h$, and $\lambda = 1m$, then the Q for a copper cavity is approximately 50,000.

TRANSVERSE LINES OF FORCE IN TUBES OF CIRCULAR CROSS SECTION

Figures 27, 28, 29, and 30 show the transverse lines of force for typical guided waves in tubes of circular cross section. The lines of force which do not remain in transverse cross sections are not easy to draw; one should visualize them as surrounding the transverse lines.

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Training Technical Personnel for War Industry

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MEMBER AIEE

THE programs of the Army and Navy for the selection and training of technical personnel for the armed forces indicate the prospect of a carefully planned and orderly flow of engineering officers into the armed services. War industry is not so fortunate. There is as yet no comparable plan for insuring the sustained and orderly flow, into our civilian economy, of the engineering talent needed to energize production in the industrial plants to which the Army and Navy look for supplies of war material.

Authorities responsible for the prosecution of the war agree that industry must have a fair share of the available supply of engineers if it is to meet the production schedules that the war effort demands. Several proposals for the selection and training of engineers for industry have been considered by the War Manpower Commission, but to date none of these has been approved or adopted by that body, although it is my understanding that the Committee of Nine which allocates colleges to the Army and Navy for specialized training has reserved 25 per cent of the available facilities for the training of engineers for industry.

This third article to appear in "Electrical Engineering" on the problem of producing engineers in wartime nominates the Engineering, Science, and Management War Training Program as a workable plan for securing leaders for the production line. Articles describing the Army Specialized Training Program and the Navy College Training Program which have already been put into operation appeared in the March issue.

Engineering students have been declared by Selective Service to be eligible for consideration by local draft boards for deferment, provided the college in which such students are enrolled certifies that they are competent and that they will be graduated on or before July 1, 1945. Students are increasingly reluctant to ask for such deferment, however, and local Selective Service Boards are likewise less willing to defer college boys when this now means that men with families must be called up in their stead. In view of these trends, it seems unlikely that industry can look forward to any adequate supply of new engineering personnel via the deferment route.

There will be a small number of college men, physically disqualified for military service, who can be trained for industry, and possibly more young women can be induced to enter engineering schools. Frankly, I am not very hopeful that large numbers of girls can be persuaded to undertake long-term curricula in engineering, because the evidence to date indicates that, whereas women are anxious to help in the war effort and will take quick training courses to prepare themselves for immediate service in industry, most of them are not interested in engineering as a career and do not want to undertake a full engineering education.

Unless the War Manpower Commission evolves some method whereby engineering students can be prepared for industry in the colleges on some plan similar to the Army and Navy specialized training programs, it is clear that our civilian economy will soon be very largely cut off from its normal sources of recruiting engineering talent. In view of the obvious difficulties in selecting equitably and training a quota of able-bodied young men specifically for civilian purposes, at a time when all other qualified young men are going into military service, I think it is unlikely that a feasible plan will be found.

If a sufficient supply of young engineers cannot be expected from the colleges, what then is the War Manpower Commission prepared to do for industry, and how is industry to solve its pressing problem of obtaining technical personnel? A program that already has helped a great deal and that can help a great deal more in the months ahead is the Engineering, Science, and Management War Training Program (ESMWT for short).

Since the supply of fully qualified engineers for industry is already small and likely to be even smaller, in the absence of any adequate flow of new blood from the engineering schools, it is clear that we must utilize at maximum efficiency the engineers still available, by providing them with assistants who can relieve them of as much routine work as possible. Such assistants can be trained under the ESMWT program for the specific tasks that industry wants them to perform, and then they can be upgraded through in-service courses for

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Essential substance of an address delivered at the AIEE Northeastern District technical meeting, Pittsfield, Mass., April 9, 1943.

W. C. White is dean of engineering, Northeastern University, and regional representative of the Engineering, Science, and Management War Training Program in New England.

larger responsibilities, as rapidly as their abilities warrant and the time available permits.

Let me outline briefly how the ESMWT program operates and what it is prepared to do for industry.

ORIGIN AND PURPOSE

Originally sponsored by the United States Office of Education at the suggestion of a group of leading engineering educators who foresaw $2^1/_2$ years ago that there would be a serious shortage of technically trained people as the defense program developed, Engineering Defense Training, as it was first called, was designed to provide short intensive courses at the college level to fit men and women for technical jobs in war industries. Limited at first to engineering, the program was broadened later to include chemistry, physics, and production supervision, and the title was changed to Engineering, Science, and Management War Training.

ORGANIZATION AND ADMINISTRATION

In a recent reorganization of the War Manpower Commission, ESMWT became one of six components of the Bureau of Training headed by W. W. Charters. The other five agencies—National Youth Administration, Training Within Industry, Vocational Training for War Production Workers, Apprentice Training Service, and Vocational Training for Rural War Production Workers—all are concerned with training at the vocational level.

This year the agencies which comprise the Bureau of Training are spending over $200,000,000 of government funds in war-production training. The $30,000,000 allocated to ESMWT is about the same sum of money that it took to operate all of the engineering schools of the country for one year in the middle 1920's, at the time of the investigation of engineering education conducted by Doctor Wickenden for the Society for the Promotion of Engineering Education.

The actual administration of ESMWT is handled with notable efficiency in the United States Office of Education under the able leadership of George W. Case, dean of the University of New Hampshire's college of technology, by a small staff, most of whom are on leave of absence from engineering faculties. Participating colleges, now over 200 in number and including all of the nation's engineering schools, determine the needs of industry in the areas that they serve, propose appropriate courses to meet these specific needs, and assist in placing the trainees where they can be most useful to the war effort.

Regional co-ordination is provided through 21 part-time regional advisers who serve without compensation and act as chairmen of committees made up of representatives of participating institutions in their areas. The whole program is a spontaneous and voluntary one in which the colleges have co-operated enthusiastically on a nonprofit basis as part of their contribution to the national welfare in this emergency. Institutions are reimbursed for the costs of offering ESMWT courses, and trainees pay no tuition but are expected to purchase their own textbooks and minor supplies.

TYPES OF COURSES OFFERED

The ESMWT program is very flexible and, within the limits of its enabling act, can serve to meet a wide variety of industrial needs. High-school graduation or the equivalent is the minimum requirement for admission to these training courses, but many of them require several years of college work or even a college degree as qualification for enrollment. Institutions are free to set up such eligibility requirements as they feel are necessary to the proper conduct of a course and to select the trainees who can be admitted, provided there is no discrimination because of sex, race, creed, or color. Wherever possible, employers have been asked to co-operate with the colleges in the selection of suitable trainees.

Two patterns of procedure have developed in the offering of ESMWT courses. In some communities representatives of the colleges have been able to secure the interest and co-operation of war industries in a very intimate working relationship, whereby the planning and offering of these courses has become in effect a joint enterprise. The manufacturers have analyzed carefully their personnel problems, estimated losses likely to occur through Selective Service in various categories, studied the particular knowledges and skills that would be needed by replacements, worked out tailor-made courses of study with members of the college faculty, assisted in the selection of trainees who would be employable after training, and finally placed the people thus trained in the company's employ.

Many times the course is taught by a specialist from industry rather than by a college teacher, and the instruction may be even given off campus, at the plant or in rented areas conveniently near it. While the courses offered are all of college grade, they are not traditional units of engineering curricula but are individually designed to meet the specific requirements of definite jobs that industry needs to fill. The plan is flexible enough to provide for training ranging from basic mathematics and mechanical drawing at one extreme to advanced mechanics, X-Ray-diffraction analysis of metals, geometrical optics, and ultrahigh-frequency techniques at the other.

It is not always possible to obtain in ESMWT courses the ideal setup, in which the trainee's entire program is preplanned, although this is the objective toward which we are striving constantly. Industrial executives are sometimes too busy to give the necessary time for such a program, frequently they can't anticipate their personnel needs adequately, and the smaller companies particularly do not have sufficient staff to warrant running special courses for their own plants alone.

To fill their needs and to provide a pool of trained

workers in fields where known shortages exist, the colleges have offered open courses in engineering drawing, motion and time study, production control, industrial safety, metallography, mathematics, tool design, electrical inspection and testing, and similar fields, and have publicized these rather widely, with the object of serving people whose value to war production would be enhanced through such training and who would not be reached otherwise. The results of such courses have been very gratifying in that large numbers of the trainees have been upgraded into more responsible jobs in the plants where they were employed or have been moved from nonessential activities into war-production jobs. Some 12,000 short courses of college grade will be offered under ESMWT this year, enrolling over 600,000 trainees.

PRE-EMPLOYMENT COURSES

Large numbers of women are being inducted into industry, and the competition for this new labor supply is extremely keen. A natural tendency of women who want to do war work, even well-educated women, will be to accept jobs immediately available or available after a very brief paid-while-you-learn training course designed to provide them with the elementary skills needed by machine operators in the production line. Such women have no desire to remain in the labor market after the war and thus have no personal advantage to gain in preparing themselves for technical service at the professional or semiprofessional level.

They can be appealed to successfully, however, to undertake such preparation as a patriotic duty, provided we make it possible for them to do so without too great a financial sacrifice. This means that industry must help in the initial selection of such trainees, must put them on its pay roll as soon as training begins, and must provide opportunity for them to advance in responsibility and in earning power through in-service training after the pre-employment program has been completed. Only through such planning will industry obtain for technical service the capable women it needs, who otherwise will tend to be absorbed in routine jobs far below their abilities.

New England industry has been very slow to recognize this problem. In many other sections of the country, particularly on the west coast, full-time ESMWT courses are being given to women trainees who are paid by the companies for which they are being trained. The courses range from 6 to 16 weeks in length and include training in mathematics, physics, production processes, drawing, and elementary engineering mechanics. Sufficient training is given in the pre-employment course to make the trainee initially useful to the company. Obviously a program of supplementary training is necessary for the further development and continuous upgrading of the new worker.

An interesting example of pre-employment training of women under ESMWT is the program currently being operated for the Army Map Service. Several hundred senior girls in women's colleges are taking an orientation course in military map making in preparation for after-graduation jobs with the Army Map Service in Washington. The course comprises an introduction to planimetric and topographic maps, map drafting, projections, military grids and map series, map-reproduction methods and photomapping in two dimensions. Since the course is only 60 hours in length and is studied, in addition to a full college load, it obviously gives the girls only a start in their new work. Further in-service training is being planned for these girls after they are placed on the job.

SUPPLEMENTARY OR IN-SERVICE COURSES

By far the largest amount of ESMWT training has been of the part-time supplementary type. This will probably continue to be true in the months to come, notwithstanding the increased number of pre-employment courses for women that are anticipated. The only way in which industry can hope to obtain the technical personnel that it must have to implement the war-production program is through a continuous process of upgrading. People with potential ability to handle work above the level of that which they are doing must be encouraged to acquire new knowledge and skills through in-service training. The colleges participating in ESMWT will co-operate gladly in organizing and supervising the appropriate courses, but they will need the guidance of industrial executives in laying out the subject-matter content and in selecting the trainees most likely to become more useful in war production as a result of the training.

A specific example may be of interest by way of illustration. One of our ESMWT representatives at Northeastern University discovered that several members of the engineering staff of a large radio-manufacturing company were very much in need of a course in ultra-high-frequency techniques. The head of our electrical-engineering department, in conference with the chief engineer of the company, worked out a combined lecture and laboratory course to meet three evenings a week for 16 weeks. Other radio manufacturers in the area were circularized about the prospective course, and many of them designated employees whom they wished to have enrolled. Incidentally, the course was limited to college graduates who had majored in electrical engineering or physics, and the trainees are expected, not to get new jobs as a result of the course, but to be more effective in their present positions.

An executive of an electrical manufacturing company that was experiencing difficulty in certain phases of radio-tube production suggested a course in glass processing. Such a course was developed and publicized by word of mouth only, but the demand for it was so great that four separate sections of the course were organized

in various suburban areas of Greater Boston. This is the type of need that ESMWT is prepared to meet.

CONCLUSIONS

ESMWT cannot and does not attempt to produce full-fledged engineering graduates capable of general professional service. Perhaps the War Manpower Commission will find a way of channeling a reasonable proportion of young fully trained engineers into war industry. Let us hope so. In the meantime our colleges and engineering schools stand ready to bridge the gap as effectively as possible through the facilities of the ESMWT program.

To summarize briefly what ESMWT is prepared to do and how industry can help if it wants such training programs:

1. The colleges participating in ESMWT can organize and offer, without cost to industry and without tuition charge to the trainees, short courses ranging in length from 6 to 16 weeks in the fields of engineering, physics, chemistry, or production supervision (cost accounting, statistics, traffic management, personnel administration, industrial management, procurement and stores, office management) to meet specific training needs.

The courses can be of the full-time pre-employment type or of the part-time supplementary type, can be given day or evening, on campus or off campus at a more convenient location for those enrolled, can be of an elementary or advanced nature, as long as the subject matter is at the college level and the trainees have at least a formal high-school education or the equivalent, and can be taught by a member of the college faculty or by a teacher selected from industry.

There is no desire on the part of the colleges to promote ESMWT courses just for the sake of building up a program. College faculties, engineering faculties especially, are going to be very busy with Army and Navy training programs, and they have no desire to add unnecessarily to their burdens. At the same time they are ready and eager to serve industry as fully as industry wants to be served in the provision of technical training.

2. Engineers who are in the key positions in industry, therefore, have the responsibility of indicating to us as clearly as possible their particular needs for trained personnel. We must depend upon them to advise us on course content and to aid us in the selection of the trainees who will be most serviceable in increasing production after they are trained. And finally, industry must make provision for paying women trainees while they are taking ESMWT full-time pre-employment courses, if such women are to be attracted to college-level technical training.

Electric Conveyances in Air-Foam Rubber Production

C. B. RISLER
ASSOCIATE AIEE

JOHN GROTZINGER
ASSOCIATE AIEE

THE manufacture of sponge-rubber forms involves the creation of bubbles inside the rubber and the necessity of maintaining their even distribution. Such a process presents the problem of handling the material very carefully at all times and with sufficient regularity and rapidity to permit the process to be performed in a production-line manner. Such a problem is posed by the material-handling system recently installed at the Akron (Ohio) plant of the Goodyear Tire and Rubber Company. The solution embodies a combination of squirrel-cage motors with dynamic braking and d-c adjustable-voltage drive with Rototrol control all closely tied together with control interlocking and actuated by numerous limit switches.

Air-foam rubber is manufactured from latex, which is mixed with other necessary ingredients to form a doughy mass. This is placed in tight molds and cured in vulcanizing ovens. This curing process must be performed under accurate time and temperature control. Upon removal from the mold, the product is complete.

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Special handling problems have arisen in the manufacture of sponge-rubber forms because of the necessity of creating bubbles inside the rubber and maintaining them in even distribution. To cope with the problem of handling the material carefully and at the same time rapidly enough to employ production-line technique, electric equipment involving a combination of squirrel-cage motors with dynamic braking and d-c adjustable-voltage drive has been developed.

MECHANICAL SYSTEM

Briefly, the mechanical equipment involved is as follows. A mixing machine and rotary platform prepare and distribute the "green" mixture. This is put into aluminum molds as they move slowly past the mixer. These molds are carried on steel frames with rollers called pallets, which are propelled along a track by lugs on a chain conveyor. This conveyor shall be referred to as the pouring conveyor. After being filled, the lids of the molds are automatically closed and held tightly shut as the pallets move to the elevator. On the elevator the pallets are stacked two to a tier and seven tiers high. When this total of 14 pallets has been assembled, they are moved by a pusher onto the transfer car, which puts them in a vulcanizing oven.

The vulcanizing complete, the pallets are again placed on the transfer car, which takes them to the "lowerator," a device similar to the elevator in physical appearance but which performs just the reverse function. It takes the stack of 14 pallets and passes them out one at a time onto the stripping conveyor. This conveyor, like the pouring conveyor, is of the chain type with lugs which engage the pallets and push them along a permanent track. On this stripping conveyor, the completed air-foam products are removed from the molds, which are then cleaned and prepared to repeat the above cycle. At the end of the stripping conveyor, the pallets pass onto a cross conveyor which transfers them to the pouring conveyor at the approach to the pouring point. This completes the cycle, which is repeated continuously.

THE ELECTRIC SYSTEM

The electric equipment for the various drives is next considered in detail. The mixer and ovens are considered as a part of a manufacturing process rather than material-handling equipment and hence are not within the scope of this article.

A common characteristic of all the motors is the necessity for protection from falling objects and pieces of rubber in the process. To secure this protection, the driving motors are either of dripproof or splashproof construction and are rated on the basis of a 50-degree centigrade rise in continuous operation, in accordance with National Electrical Manufacturers Association standards. The adjustable-voltage motor-generator set for driving the transfer car is of the open-protected construction. Spring-set solenoid-released shoe brakes are used for all drives to serve both a retarding and holding purpose. Open floor-mounted brakes are used.

Pouring Conveyor. The pouring conveyor operates continuously, at constant speed. The load, when under full operation, is, for all practical purposes, constant.

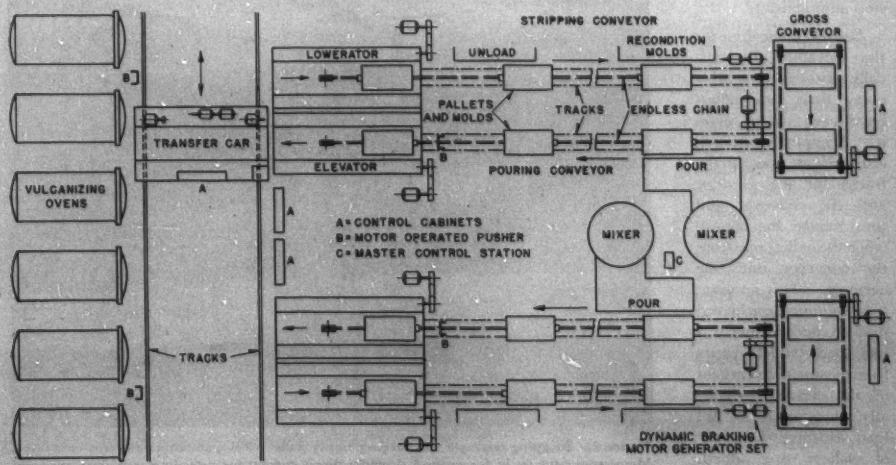

Figure 1. Layout showing relative location of apparatus

With changes in the size of the product, the amount of material placed in the mold will change but because of the basic load of the pallet and mold, the change in load on the drive motor by no means will be proportional. Because of the mechanical construction of the track, antifriction bearings on the pallets, and the use of a chain type of conveyor, the starting friction is reduced from that required on usual conveyor drives. Requirements on the electric equipment are, therefore, for a motor with normal starting torque, uniform speed under all load conditions, and for a motor that can operate continuously under full load. These conditions are met by the 7.5-horsepower general-purpose 1,750-rpm squirrel-cage motor. This motor combines simplicity, strength, and the perfect performance characteristics for the job. The holding brake is rated 50-pound-feet torque continuously.

The control for the pouring conveyor consists of across-the-line starting and d-c dynamic braking for rapid retardation. In this scheme, d-c potential is applied to two of the motor terminals. This sets up a stationary field which induces current in the rotor when it is turned. This current dissipates the energy of rotation as heat in the motor rotor. The equipment involved is a three-pole running contactor, a two-pole dynamic-braking contactor, an overload relay, and a time-limit relay to remove the d-c voltage and set the brake to bring the drive to a final stop.

Control is secured through a main push-button station located at the pouring position. As expected in an involved and interlocked system of this nature, this drive is so interlocked with the elevator that, should the elevator become jammed or fail to operate, the loading conveyor will stop automatically.

Elevator. The drive for the elevator automatically must raise one layer every time two pallets have been placed upon it. Accurate spotting is required to line up the tracks on the elevator with the conveyor and thus reduce the bounce when the pallets pass from the conveyor onto the elevator. This accurate spotting must be achieved under a condition of varying load, which varies from the small friction load of the elevator, gradually increasing to full load as successive pairs of pallets are added. The mechanical construction of the elevator is such that this drive does not have to be reversed.

The requirements of operation under varying loads with approximately the same speed under all conditions from basic friction to maximum is met by the use of a 15-horsepower, squirrel-cage gear motor. This consists of a motor close-coupled to a set of double-reduction gears with 87-rpm output speed, giving in a small compact unit an electric drive with a low output speed. This gear motor is controlled by a nonreversing across-the-line type of starter with which, in order to secure the quick accurate stopping desired and reduce excessive wear on the 25-pound-foot torque brake, d-c dynamic braking is again employed. This, together with the employment of hatchway-type limit switches to initiate starting and stopping, accounts for the precision achieved. The impulse to hoist the elevator is given by hatchway-type limit switches when two pallets have been placed on a given tier. Another limit switch geared to the elevator drive functions when the elevator has been raised one level to stop the hoist motion. Proper limit-switch protection and interlocking is provided so that when the elevator has been filled to capacity, it will not operate until emptied and the loading conveyor will be stopped to prevent more pallets from being forced onto the elevator.

Pusher. A pusher is provided to remove the pallets from the elevator to the transfer car. Because of the necessity of handling the material carefully, the pallets must be pushed slowly and gently. However, in order to prepare for the next loading of the elevator, the pusher

Figure 2. Stripping conveyor discharging empty pallet with open mold onto cross conveyor. Motor-generator set in foreground provides direct current for retarding cross conveyor and elevator motors

must be returned to its original position at a faster speed. This imposes variable-speed reversing service on the pusher drive. Since the function is to push the pallets on their rollers in a horizontal plane normal starting torque is sufficient. This drive is best handled by a 1.5-horsepower constant-horsepower two-speed two-winding 1,150/435-rpm squirrel-cage motor.

The control is of the across-the-line type, the motor being placed on the slow speed winding for pushing, retarded by d-c dynamic braking and returned on the high-speed winding. The transfer-car operator initiates the pusher drive from a push-button station located at the loading position. Interlocking is provided to prevent operation of the pusher unless the transfer car is in the proper position to receive the pallets. Furthermore, a hatchway limit switch automatically reverses the pusher when the pallets have been placed on the transfer car, and another limit switch stops the pusher when it returns to its normal position.

Transfer Car. The transfer car consists of a platform which moves on a track transverse to the pouring and stripping conveyors. To maintain the accuracy of limit-switch settings against slipping wheels, the car is provided with double-flanged wheels riding on a rail and is propelled by a pinion engaging long racks placed on the floor. On this car is located a cage which receives the 14 pallets stacked in the elevator. Upon reaching the oven a "gangplank" is extended from the transfer car to bridge the gap between the car and the oven. The cage containing the pallets is then pushed along the tracks from the transfer car into the oven, the "gangplank" withdrawn, and the car moves on to perform another loading or unloading operation. Driving the transfer car involves cushioned acceleration and extremely accurate spotting of the car under widely varying load conditions. Furthermore, this must be a reversible drive and capable of just as accurate spotting after traveling 2 feet as 20.

To meet these difficult requirements, an adjustable-voltage d-c drive is employed. This consists of driving the car with a 10-horsepower 250-rpm shunt-wound d-c motor. The d-c energy is supplied from a unit-frame motor generator set (25-horsepower squirrel-cage motor, 10-kw adjustable-voltage d-c generator, 2.5-kw 230-volt d-c exciter) located on the transfer car. With this type of drive, smooth acceleration is possible, and the characteristic of constant speed for widely varying loads can be readily obtained. To meet the accurate spotting requirement, a Rototrol maintains constant speed when approaching a final stopping point regardless of the load on the car. This Rototrol is an auxiliary rotating generator with especially designed, balanced field arranged in a Wheatstone-bridge circuit to react with great sensitivity to varying speeds of the motor. The Rototrol is driven by a small three-phase squirrel-cage motor and rotates at all times except final shut-down of the car. The Rototrol adjusts the field strength of the generator to effect control on the speed of the motor. The transfer car accelerates automatically under the control of inductive time limit relays, proceeding at full speed to the desired point. On approaching this point, a slow-down limit switch is engaged, and the transfer car is driven at a predetermined slow speed under control of the Rototrol as already described. At this slow speed, it is possible to set the final-stop limit switches and adjust the brake torque so that the car will always stop at the desired position. Slow down and final-stop limit switches are of the hatchway type and mounted on the underside of the car.

Figure 3. Transfer car and "lowerator" showing construction of each and location of electric equipment on car. Note pusher moving pallets from car to "lowerator"

Because of the nature of the operation, it is never necessary to operate the transfer car at the same time that the cage or "gangplank" is being moved. This makes possible the use of the adjustable-voltage drive for both of the motions on the transfer car and a reduction in the total amount of electrical equipment required. The

motor generator set is common for both of the drives, individual motors being required for the transfer car drive and the unloading drive. This is spoken of as the unloading drive since a single 5-horsepower 1,150-rpm shunt-wound d-c motor is used first to move the "gangplank" into position and, when this has been performed, to move the cage along the cross tracks into the oven. Adjustable-voltage drive is particularly suitable for this motion also in that the cage must be accelerated smoothly and gently handled.

Figure 4. View of transfer car showing Rototrol mounted on control panel and operator's cab

Since operation of the transfer car cannot be predetermined and assigned any definite routine, and also, since it is advisable to have the operator as close to a delicate operation of this nature as possible, it was decided to have him ride on the transfer car. All of the motions including unloading are automatically controlled with the operator merely selecting, by push button, the oven, loading, or unloading station, to which he desires the transfer car moved. The unloading drive initiated by a push button in the operator's cab is controlled by a traveling nut limit switch, which determines the location of the accelerating and retarding points, in addition to the final stopping points.

The drives for the "lowerator" and its associated pusher, are duplicates of those for the elevator and its pusher, with the exception of such requirements as to perform just the opposite duty. The "lowerator" and both pusher control panels are located with the elevator panel at the vulcanizing end of the conveyor. The details of these drives are so similar that it is not necessary to describe them further.

The stripping conveyor is directly coupled to the pouring conveyor and operated by the same motor and speed reducer. This drive has already been discussed.

Cross Conveyor. At the opposite end from the ovens, a cross conveyor is used to transfer the pallets from the stripping to the pouring conveyor. The requirement is that the cross conveyor must line up a section of track with the track on the stripping conveyor so that the pallets may be placed upon it; then, having completed the travel, it must line this pallet up in such a position that it will be transferred onto the track of the pouring conveyor. This calls for accurate stopping of a nonreversing drive. This necessitated the use of d-c dynamic braking in a manner similar to that in which it was used on the elevator and "lowerator" drives. The conveyor is operated by a 5-horsepower squirrel-cage gear motor, with an output speed of 62 rpm. This motor is started directly across-the-line, and its action is initiated automatically by a hatchway-type limit switch when the pallet arrives on the cross conveyor. It is automatically retarded, and finally stopped by limit-switch action when it has travelled the desired distance.

The direct current for the dynamic braking excitation of the elevator, "lowerator," pushers, loading, stripping, and cross conveyors squirrel-cage motors is supplied by a single 15-kw 125-volt 1,750-rpm a-c to d-c motor generator set driven by a squirrel-cage motor. This motor generator set is started across-the-line, provided with overload protection and sufficient metering and voltage-adjusting equipment to maintain a proper d-c voltage. An interlocking relay is provided to prevent the operation of any of the associated drives, unless the source of the direct current is available for the dynamic braking. The control panels for the cross conveyor, main conveyors, and braking d-c motor generator sets are located at the pouring end of the main conveyors.

In general, the two main conveyors are controlled from the main push-button station at the loading position. The elevator and "lowerator" operate automatically as does also the cross conveyor. The pusher both for the "lowerator" and elevator are operated from push buttons located within reach of the transfer-car operator. All of these associated drives are, of necessity, interlocked to prevent any jamming or destruction of material, pallets, or conveying equipment. Numerous emergency stop buttons are located about the stripping positions.

Completely co-ordinated, the individual drives function with clockwork precision as gears in a machine to interchange pallets in a smooth stream from the time they receive the "green" latex until they have discharged their finished air-foam product and are again in a position to receive another charge.

INSTITUTE ACTIVITIES

National Technical Meeting Program Enlarged Again to Aid War Effort

An enlarged technical program of 26 sessions and conferences, as compared with a maximum of 20 sessions and conferences for the previous year, will be held in Cleveland, Ohio, June 21–25. The meeting headquarters will be in the Hotel Cleveland. In accordance with AIEE wartime policies as adopted by the board of directors all programmed social activities have been omitted. However, there will be opportunity for informal get togethers, and members desiring to participate should inquire at the registration desk.

In addition to the 26 sessions and conferences, the conference of officers, delegates, and members will be held both in the morning and afternoon on Monday. The annual meeting will take place Tuesday morning.

TECHNICAL SESSIONS AND CONFERENCES

Many of the sessions and conferences are directly or indirectly related to the war effort. The details of design and special problems in connection with electrical equipment for aircraft will be presented in a session and a conference. Wartime emergency loading of conductors will be the subject of another session. Closely allied to the question of overloading will be still another session, which has to do with transformers. Several conferences will deal with teaching aids in specialized training, experiences and problems in military specialized training, and the teaching of ultrahigh frequency. Also, the part which electricity plays in the industrial-fabrication end of the war effort will be brought out in the session on electronics in industrial power applications and in the conference on resistance welding and its associated power-supply system.

In various sessions eight wartime guides or interim reports, which treat the application and operation of electrical equipment and apparatus under war conditions, will be presented. These wartime guides or interim reports have been developed by AIEE technical committees and subcommittees in collaboration with the standards committee as a wartime emergency measure to conserve critical materials. In addition, the Association of Edison Illuminating Companies subcommittee on wartime temperatures for power cables in service will present a guide on that subject.

There will be a conference on civic affairs and another on the subject of "How Can the Institute Render Greater Service to its Latin American Members?"

INSPECTION TRIPS

Because of wartime restrictions in the matter of transportation and plant protection, only two inspection trips are scheduled. These are directly associated with two of the technical conferences. It is necessary that firm commitments for transportation and plant-protection identification be made in advance, and the committee on transportation and trips requests that advance registrations for these trips should be made by writing J. J. Tesar, in care of Cleveland Electric Illuminating Company, Cleveland, Ohio, chairman, trips and transportation committee. These inspection trips will be limited to United States citizens, and those participating are reminded to have their birth certificates or other proof of citizenship with them. The Ohio Crankshaft Company will be visited, and details relative to induction-heating processes will be shown. Another trip will be to Nela Park, the lighting laboratory of General Electric Company.

ADVANCE REGISTRATION

Members who have received an advance registration card should fill in and return it promptly, if they have not already done so. This will permit the registration committee to have badges ready and will prevent congestion at the registration desk. In accordance with regular practice, a registration fee of two dollars will be charged all nonmembers, excepting enrolled students and the immediate families of members.

HOTEL RESERVATIONS

Hotel reservations should be made by writing directly to the hotel preferred. For convenience, a room registration card for the Hotel Cleveland, meeting headquarters, was included with the mailed announcement sent to most members.

COMMITTEES

Members of the national technical meeting committee and chairmen of subcom-

The Cleveland Art Museum in the eastern park section of the city of Cleveland where the AIEE national technical meeting will be held June 21–25, 1943

AIEE National Technical Meeting,

● **ABSTRACTS** of papers appear on pages 266–71 of this issue.

● **PRICES** and instructions for securing advance copies of these papers accompany the abstracts. Only numbered papers are available in pamphlet form.

Monday, June 21

9:00 a.m. Registration

10:00 a.m. Conference of Officers, Delegates, and Members

J. M. Thomson, vice-chairman, sections committee, presiding

Chairman's opening statement

Address, "Impressions Obtained From My Visits to the Sections During the Past Year." **H. S. Osborne**, president

Address, "How the Institute Is Getting Along in Membership and Finances." **H. H. Henline**, national secretary

Report, "What the Sections Committee Has Been Doing in South America." Subcommittee, **O. C. Brill**, chairman; **M. S. Coover**

Address, "How the Mexico Section Is Getting Along"

Address, "I Am an American." **A. Boyajian**, General Electric Company

Report, "Development of Subsections." Subcommittee, **E. W. Schilling**, chairman; **C. A. Faust**

Report, "Other Activities of the Sections Committee During the Past Year." **E. T. Mahood**, chairman, sections committee

2:00 p.m. Clinic on Section Operation and Management of Larger Sections (More Than 300 Members)

G. W. Bower, presiding

Explanation of "clinic" plan and introduction of members of sections committee present

R. M. Pfalzgraff, vice-chairman, program subcommittee

Discussion by delegates

2:00 p.m. Clinic on Section Operation and Management of Smaller Sections (Less Than 200 Members)

W. J. Gilson, vice-president-elect, Canadian District, presiding

Explanation of "clinic" plan and introduction of members of sections committee present

J. M. Thomson, chairman, program subcommittee

Discussion by delegates

Tuesday, June 22

10:00 a.m. Annual Meeting

President Harold S. Osborne, presiding

Address by **H. W. Green**

Board of directors' report (in abstract), **H. H. Henline**, national secretary

National treasurer's report, **W. I. Slichter**

Committee of tellers' report on election of officers

Presentation of president's badge; response from **President-Elect Nevin E. Funk**

Presentation of prizes for papers

Presentation of Lamme medal to **Joseph Slepian**

President's address, **Harold S. Osborne**

2:00 p.m. Conference on Civic Affairs

43-122-ACO. The Engineer's Interest in City Planning. Report of the conference on city and regional planning at the AIEE North Eastern District technical meeting, Pittsfield, Mass., April 8. **F. A. Cowan**, vice-chairman, technical program committee

Speakers: **F. A. Cowan, H. W. Green, J. T. Howard**

2:00 p.m. Power Generation

43-93-ACO. Interim Report of Emergency Measures to Increase Output of Generating Equipment and Systems. AIEE committee on power generation

CP.** Tentative Specification for Speed Governing of Steam-Turbine Generators Rated Not Less Than 10,000 Kw. Report of Joint AIEE–ASME Committee on a Proposed Specification for Prime-Mover Speed Governing

2:00 p.m. Conference on Resistance Welding and Its Associated Power-Supply System

This will provide an opportunity to present problems arising from the extended use of resistance welders in industry today. Industrial engineers are to be encouraged to present their problems. Speakers will represent the manufacturers of resistance welders and control equipment, public utilities companies, and industrial users. Topics of discussion will be:

CP.* Resistance Welders, Characteristics, Controls, and Auxiliary Equipment

43-121. Automatic Voltage Compensator for Resistance-Welding Control. **E. M. Callender** and **R. S. Phair**, Edward G. Budd Manufacturing Company

CP.* Adequate Power-Supply System for Resistance Welders, with discussion on such factors as low voltage, lighting flickers, low power factor, and load factor; also Various Methods of Correcting Load Characteristics

CP.* Application of Series Capacitors to Resistance Welding Loads

2:00 p.m. Conference on Safety

Any time lost through accident is a war-manpower problem. In this conference emphasis will be on the safety program of the smaller electrical-manufacturing and utility organizations. After presentation of prepared papers ample time will be provided for round-table discussions.

43-94-ACO†. Practical Accident Prevention in Small Groups. **O. S. Hockaday**, Texas Electric Service Company

Wednesday, June 23

10:00 a.m. General Session

2:00 p.m. Arc-Furnace Control and Transients

43-97. A Study of Voltage Transients in Arc-Furnace Circuits. **J. B. Hodgson** and **J. B. Rice**, Allis-Chalmers Manufacturing Company

43-98. Practical Calculation of Electrical Transient on Power Systems. **R. D. Evans** and **R. L. Witzke**, Westinghouse Electric and Manufacturing Company

43-95-ACO. Arc-Furnace Control by Regulex Exciters. **T. B. Montgomery** and **T. H. Blodgworth**, Allis-Chalmers Manufacturing Company

43-96. Rotating Regulator for Arc Furnaces. **R. A. Geiselman, C. C. Levy**, and **W. R. Harris**, Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference on "How Can the Institute Render Greater Service to Its Latin American Members?"

CP.* International Electrical Standards. **L. F. Adams**, General Electric Company

CP.* Relations Between Latin American and United States Standardizing Bodies, With Particular Reference to Electrical Standards. **Alberto Magno-Rodrigues**, American Standards Association

2:00 p.m. Synchronous Machinery

43-76. Pole-Face Loss in Solid-Rotor Turbine Generators. **W. W. Kuyper**, General Electric Company

43-89. The Quadrature Synchronous Reactance of Salient-Pole Synchronous Machines. **R. V. Shepherd** and **C. E. Kilbourne**, General Electric Company

43-99. The Calculation of Unbalanced Magnetic Pull in Synchronous and Induction Motors. **R. C. Robinson**, Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference of Student Branch Counselors

This conference will deal with Student Branch problems, particularly as related to postwar programs.

Thursday, June 24

9:30 a.m. Induction Machinery

43-83. A New Type of Adjustable-Speed Drive for A-C Systems—II. **A. G. Conrad** and **P. F. Ordung**, Yale University, and **S. T. Smith**, Naval Research Laboratory

43-100. Distribution Factors and Pitch Factors of the Harmonics of a Fractional-Slot Winding. **M. M. Liwschitz**, Polytechnic Institute of Brooklyn

43-82. Critical Material Conservation in Induction-Motor Manufacture. **H. M. Hobart**, Consulting Engineer

CP.* Allowable Temperature Rise of Totally Enclosed Fractional-Horsepower Motors

American Standard C50, covering American standard for rotating electrical machinery, has been revised and is being reissued. It will recognize an allowable temperature rise for totally enclosed fractional-horsepower motors five degrees centigrade higher than that recognized for integral-horsepower motors. This difference is of definite concern to a number of design engineers. The purpose of the conference session is to encourage a full discussion of this matter.

9:30 a.m. Switching Equipment and Supervisory Control

43-84. Interim Report on Application and Operation of Automatic-Reclosing Equipment on Steel Feeders. Subcommittee on a-c automatic-reclosing equipment, AIEE committee on automatic stations

*CP: Conference presentation; no advance copies of papers available; not intended for publication in *Transactions*.

†ACO: Advance copies only available; not intended for publication in *Transactions*.

CP: Conference presentation; copies available on request from **M. J. Steinberg, Consolidated Edison Company of New York, Inc., 4 Irving Place, New York, N. Y.

Cleveland, June 21-25, 1943

43-101. Interim Report on Characteristics and Performance of Conductors for Supervisory Control and Telemetering. Subcommittee on characteristics and performance of conductors for supervisory control and telemetering, AIEE committee on automatic stations

43-102. The Cause and Control of Some Types of Switching Surges. **T. W. Schroeder**, General Electric Company

43-86. Experience With Oil-Circuit Reclosers on REA Systems. **L. M. Moore** and **B. O. Watkins**, Rural Electrification Administration

43-103. A New High-Interrupting-Capacity Fuse for Voltages through 138 Kv. **H. H. Fahnoe**, Westinghouse Electric and Manufacturing Company

9:30 a.m. Conference on Agricultural Electrification

CP.* The Farmer and His Electricity. **Grover C. Neff**, president, Wisconsin Power and Light Company

CP.* Evolution in Agriculture. **Frank E. Watts**, Farm Journal and Farmers' Wife

CP.* Application Engineering—The Key to Increased Farm Production. **George W. Kable**, editor, *Electricity on the Farm*.

CP.* Progress in Serving Oklahoma Farms. **Roy E. Hayman**, Oklahoma Gas and Electric Company

CP.* Chemurgy—Its Place in This War and After It. **L. F. Livingston**, E. I. duPont de Nemours and Company

Alternate subject (time permitting)

CP.* The Care and Maintenance of Electric Farm Equipment. **A. H. Hemker**, General Electric Company

9:30 a.m. Conference on Teaching Aids in Specialized Training

9:30 a.m. Conference on Induction Heating

Speakers: **H. B. Osborn, Jr.**, **P. D. Zottu**, **W. E. Beaninghoff**, **J. P. Jordan**

1:30 p.m. Conference on Experiences and Problems in Military Specialized Training

CP.* Safety Engineering Instruction at Oklahoma A and M College. **A. Nasser**, Oklahoma Agricultural and Mechanical College

2:00 p.m. Wartime Emergency Loading of Conductors

43-85. Safe Ratings for Overhead Line Conductors. **L. M. Olmsted**, Duquesne Light Company

43-104. Guide for Wartime Conductor Temperatures for Power Cables in Service. Association of Edison Illuminating Companies subcommittee on wartime temperatures for power cables in service

43-105. Interim Report—Emergency Overloads on Overhead Conductors. Working group on towers, poles, and conductors, transmission subcommittee, AIEE committee on power transmission and distribution

43-77. The Effect of Corona on Coupling Factors Between Ground Wires and Phase Conductors. **G. D. McCann**, Westinghouse Electric and Manufacturing Company

2:00 p.m. Selected Subjects

43-120. Submarine Switching Systems for Teleprinter Tie Lines. **F. L. Carrie**, Western Union Telegraph Company

43-81. A Capacitance Bridge for Determining the Ratio and Phase Angle of Potential Transformers. **H. W. Bousman** and **R. L. Ten Broeck**, General Electric Company

43-106. Formulas for Calculating Short-Circuit Forces Between Conductors of Structural Shape. **T. J. Higgins**, Illinois Institute of Technology

43-107. A Method for Determining the Normal Modes of Foster's Reactance Networks. (Presentation by title) **W. R. LePage**, Radio Corporation of America

43-108. A Method for Correlating Duty-Cycle Tests on Solenoids. **J. E. Ryan**, General Electric Company

43-78. Adequate Electrical Maintenance Essential to Transportation. **W. J. Clardy**, Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference on Wartime Influences in Lighting

3:30 p.m. Conference on Teaching of Ultrahigh Frequency

Speakers: **J. G. Brainerd**, **H. J. Reich**, **W. C. Osterbrock**

7:00 p.m. Dinner—Jointly with the Cleveland Section, Institute of Radio Engineers

Address: "Frequency Modulation Versus Amplitude Modulation at High Frequencies." **Raymond Guy**, Radio Facilities Engineer, National Broadcasting Company

Friday, June 25

9:30 a.m. Carrier Current and Miscellaneous Subjects

43-80. Application of Carrier to Power Lines. **F. M. Rives**, General Electric Company

43-91. Carrier-Current Differential Protection for Transformer Banks. **T. A. Cramer**, General Electric Company

43-110. A Simple Method for the Determination of Bushing-Current-Transformer Characteristics. **S. D. Moreton**, General Electric Company

43-111. Report on Application of Lightning-Protective Devices in Wartime. Lightning arrester subcommittee, AIEE committee on protective devices

43-112. Frequency Modulation for Power-Line Carrier Current. **E. W. Kenefake**, General Electric Company

9:30 a.m. Electrical Equipment for Military Aircraft

43-123. Aircraft Electric-Power Supply System. **J. E. Yarmack**, International Telephone and Radio Manufacturing Corporation

43-124. Characteristics and Applications of the General Electric Company Selenium-Rectifier Cells. **E. A. Harty**, General Electric Company

43-125. Fundamental Principles of Amplidyne Applications. **F. E. Crever**, General Electric Company

43-126. Design Relationships for D-C Generators for Use in Aircraft. **S. R. Bergman**, General Electric Company

43-127. Aircraft Inverter Construction. **C. T. Button**, Holtzer-Cabot Electric Company

9:30 a.m. Electronics in Industrial Power Applications

43-113. The Testing of Mercury-Arc Rectifiers. **H. L. Kellogg** and **C. C. Herskind**, General Electric Company

43-90. Theory of Rectifier—D-C Motor Drive. **E. H. Vedder** and **K. P. Puchlowski**, Westinghouse Electric and Manufacturing Company

43-114. Operation of Nonsalient Pole-Type Generators Supplying a Rectifier Load. **M. D. Ross** and **J. W. Batchelor**, Westinghouse Electric and Manufacturing Company

43-115. Load Pickup by a Group of Ignitron Rectifiers. **L. W. Morton**, General Electric Company, and **D. I. Bohn**, Aluminum Company of America

43-116. Thyratron Motor Control. **E. E. Moyer** and **H. L. Palmer**, General Electric Company

9:30 a.m. Transformers

43-88. High-Voltage Power-Transformer Design. **M. B. Mallett**, English Electric Company of Canada, Ltd.

43-87. Interim Report on Overloading Distribution Transformers. Transformer subcommittee, AIEE committee on electrical machinery

43-109. Interim Report on Overloading Current-Limiting Reactors. Transformer subcommittee, AIEE committee on electrical machinery

CP.* Normal and Emergency Loading of Power Transformers. **H. B. Keath** and **W. Godin**, Wagner Electric Corporation

2:00 p.m. Relaying

43-117. A New High-Speed Balanced-Current Relay. **V. N. Stewart**, General Electric Company

43-79. Pilot-Wire Relaying on a Metropolitan System. **T. G. LeClair** and **E. L. Michelsen**, Commonwealth Edison Company

43-92. Distance Relay Protection for Subtransmission Lines Made Economical. **L. J. Audlin**, Central New York Power Corporation, and **A. R. van C. Warrington**, General Electric Company

43-118. Relay Protection of Tapped Transmission Lines. **M. A. Bostwick** and **E. L. Harder**, Westinghouse Electric and Manufacturing Company

43-119. Interim Report on Application and Operation of Out-of-Step Protection. Working group of relay subcommittee, AIEE committee on Protective Devices

2:00 p.m. Electrical Equipment for Military Aircraft

43-128. Aircraft Circuit Breakers. **C. W. Kuhn**, Cutler-Hammer, Inc.

43-129. Principles of Aircraft Electric-Motor Protection. **V. G. Vaughan**, Spencer Thermostat Company

43-130. Manual Switches for Aircraft. **R. A. Millermaster**, Cutler-Hammer, Inc.

43-131. Aircraft Contactors. **F. J. Russell** and **A. P. Charbonneau**, Cutler-Hammer, Inc.

43-132. Radio Noise Filters Applied to Aircraft. **C. W. Frick** and **S. W. Zimmerman**, General Electric Company

2:00 p.m. Conference on Operating Experiences With Mercury-Arc Rectifiers

Subject Matter:

(*a*). Industrial application of rectifiers

(*b*). Large rectifier stations

(*c*). Rectifier cooling systems

(*d*). Rectifier harmonics

mittees making arrangements are: W. E. Wickenden, *chairman;* G. R. Canning, *vice-chairman;* B. W. David, *secretary-treasurer;* D. Ramadanoff (secretary-treasurer, Cleveland Section). Subcommittee chairmen: L. T. Blaisdell, *finance;* E. A. Rossrucker, *publicity;* J. C. Strasbourger, *hotels;* A. J. Kres, *registration and information;* P. L. Hoover, *meetings and papers;* J. J. Tesar, *transportation and trips.*

AIEE Prepares Wartime Guides for Electrical Apparatus

A major AIEE activity at the present time is the preparation of wartime guides and reports covering the technical phases of the application and operation of electrical apparatus. This is in accordance with the decision of the board of directors that the Institute should devote its services in every way possible toward aiding directly the war effort.

A number of these Guides and Reports will be presented during the week of June 21 at the national technical meeting in Cleveland along with the general theme of wartime problems and conservation of materials. Consequently, it seems well to review briefly their history, purpose, and status.

Soon after the outbreak of hostilities the Institute recognized that the war emergency would require that maximum possible use be made of all existing equipment and that a minimum amount of critical materials would be available for use in the manufacture of new equipment. This situation emphasized the great importance of nationwide usage of industry standards and standard apparatus. Since the Institute's membership is very broad, and its committees are composed of representatives of users, manufacturers, educators, and others, it is particularly well fitted as an established standardizing body to handle for the industry at large such technical matters as preparation of war-emergency standards or technical-application guides as may be required for "duration" use.

For many years the Institute has promulgated the development of electrical standards and test codes, both directly and through the American Standards Association. Experience has shown that the Institute's standardizing procedure is direct and expeditious, oftentimes resulting in the completion within a relatively short time of standards or reports on standards which served the industry and were later given consideration by ASA in the preparation of an American Standard. These standards have established criteria for electrical-apparatus rating, performance, procedure, and test guarantees. These have been considered pre-eminent throughout the industry for many years. Their preparation has required careful deliberation and study by engineers recognized as authorities in their respective fields. However these standards and test codes are of a fundamental technical nature and do not lend themselves to short-term changes without upsetting seriously design, manufacturing, application, and operating practices. This is an important aspect in considering the formulation of war-emergency standards or guides.

After careful consideration of the wartime needs and the many problems involved in the preparation and use of emergency standards, the standards committee decided that in a great majority of cases the wartime situation could be taken care of effectively by the preparation of a number of wartime guides and interim reports covering the technical application of various types of standard electrical apparatus. In a few instances emergency substitutions or modifications of present standards may be required. Therefore the standards committee in collaboration with the technical program committee recommended that the Institute's technical committees actively proceed with this work.

This wartime basis required many new concepts in the selection, application, and operation of electrical apparatus and equipment in order to take full advantage of all favorable factors, such as ambient temperature and other service conditions, conservative design margins, load factors, use factors, supplemental cooling, spare equipment.

The technical committees of the Institute have been engaged very actively in this undertaking for about a year and have produced a vast amount of data of direct practical value to both manufacturers and users—especially to the war industries. These reports and guides are intended to promote the fullest use of sound engineering principles in the design, application, and operation of the various types of electrical apparatus. Although the impetus for their preparation is coming from the present war emergency and the necessity to conserve critical materials, nevertheless it is recognized that since they are being prepared on a sound engineering basis, much of the work may be of use even after the war.

The guides and reports are intended to present a general consensus of typical American engineering practice in the selection and co-ordination of equipment for various types of electric-power systems under the conditions prevailing during the present war emergency. They also present information on the performance of electrical equipment under operating service conditions which differ from those usually considered as "normal." Thus they indicate the broad adaptability of *standard* apparatus to special conditions as well as the more usual applications. The economic importance of this should be clearly evident with respect to broader usage of specific apparatus and the ultimate reduction in manufacturing costs, delivery time, and installation expense.

Experience has indicated that this work is resulting in the more widespread use of standard apparatus for all kinds of applications and in many instances the heavier loading of existing apparatus such as generators, breakers, transformers, reactors, and cables. All of this leads to very appreciable savings of critical materials and oftentimes eliminates the necessity for construction changes.

Users of electrical apparatus should not feel that in the past they have been too conservative in their applications, as the guides also call attention to the penalty (in terms of shortened life expectancy) which may be incurred by the operation of apparatus beyond its specified nameplate rating.

Each of the guides or reports is to carry a foreword explaining its purpose, and stating that ". . . it has been prepared by a technical committee for the purpose of making essential information immediately available to war industries, thus furthering the conservation of valuable materials and labor for the war emergency, that the information is educational in character and in no way mandatory, and that at the present time it is not intended as a 'standard' and has not yet been formally approved by the standards committee nor by the board of directors."

The criterion upon which they have been accepted is that they are timely and have been prepared for the information of manufacturers and users for the "duration." After the war emergency they will be re-

Subject	Paper Number	Price by Mail (Cents)	Published in "Transactions"
Shunt capacitors	43-48	30	May 1943, p. 220
Power cables	43-104	*	
Circuit breakers and switchgear	43-69	15	†July 1943
Generating equipment and systems	43-93	20	
System grounding impedance	43-5	15	Jan. 1943, p. 17
Industrial-power distribution systems	43-40	70	
Electric motors and motor controllers	43-62	15	
Automatic-reclosing equipment on stub feeders	43-84	20	
Power transformers and regulators	42-156	15	Sept. 1942, p. 692
Distribution transformers	43-87	15	
Current-limiting reactors	43-109	*	
Lightning arresters	43-111	*	
Conductors for supervisory and telemetering	43-101	*	
Out-of-step relay protection	43-119	*	

* Not yet available. † Tentative schedule.

considered by the standards committee and the committees which prepared them and then will be approved, revised for normal use, or rescinded. Early availability of the guides is a vital necessity in order that they may be of the most value in the war effort. The technical committees have been urged to present these guides and reports at Institute meetings at the earliest opportunity. After presentation and discussion, they will be given further consideration and review.

One war-emergency standard has been prepared—(War Emergency Modification of AIEE Standard 45, "Recommended Practice for Electrical Installations on Shipboard"). However, the guide and report procedure is being followed in other cases in preference to the preparation of special war-emergency standards which might involve extensive redesigning and drastic changes in manufacturing and application practices at this time. It is believed that the guides accomplish the maximum conservation of critical materials, since they provide for the greatest use of existing equipment and systems, as well as new equipment, without changing the fundamental basis on which the present standards have been prepared.

At the present time wartime guides or interim reports on the subjects listed in the table, page 258, are available or will be completed in time for presentation at the national technical meeting to be held in Cleveland in June. Copies of those available in pamphlet form may be obtained by Institute members from AIEE headquarters by referring to the paper number as listed in the table.

Successful Wartime Meeting Held by AIEE South West District

Despite difficulties imposed by wartime conditions, a highly successful technical meeting was held by the AIEE South West District, April 28–30, at Kansas City, Mo. Concurrently the annual engineering conference of the Missouri Valley Electric Association was held at the same headquarters hotel, the Continental. As many of those who attended the combined meetings would have attended both if they had been held separately, the result was a great saving in time, expense, and the use of critical transportation facilities. The two groups participated jointly in several features, notably two general sessions, two luncheons, and two dinners. The AIEE Student Branches within the District also held their annual conference during that period and participated in some of the events of the meeting in addition to carrying out their own program.

Four technical sessions on a variety of subjects constituted the technical program of the meeting. Throughout these sessions, the emphasis was on problems directly related to war activities. Simultaneously, technical sessions were held by the MVEA, and members of both organizations attended all sessions.

Other features of the meeting included a round-table conference on Section operations and management and a meeting of the District executive committee. Details of the principal events are reported in separate items.

Total registration for both groups was 572, of which 338 were AIEE registrants. Detailed registration figures are given in the accompanying tabulation.

OPENING JOINT SESSION

Addresses by the presidents of both organizations were features of the joint general session which marked the official opening of the meeting. J. G. Thorpe, general chairman of the MVEA engineering group, presided.

In the absence of City Manager L. P. Cookingham of Kansas City, Elmer S. Pierson, president of the Vendo Company, delivered the opening address. He declared that the old idea of the West being predominantly agricultural no longer holds, especially now, and he characterized the expanded wartime manufacturing activities of the Middle West as "staggering to the imagination." He predicted that many midwest war plants will remain after the war and cited as one favorable factor the high proportion of native-born labor available in that area. He urged that special provisions be made to educate after the war the men who are now in the armed forces. These men would supply the creative thinking needed for the postwar development of those industries. This creative thinking, he said, is the only element needed, as the Middle West has available plenty of facilities and materials.

What the AIEE is doing to aid the war effort was outlined by E. T. Mahood, AIEE vice-president representing the South West District. He first described briefly the objectives of AIEE and of the local, District, and national meetings held by the respective groups within the Institute. Meeting programs now are geared to war problems, and many joint meetings with other groups are being held. One of the most important technical activities he mentioned was the development of wartime guides for the application of electrical equipment, now being prepared by AIEE technical committees under sponsorship of the AIEE standards committee (*page 258*). He said that many requests for assistance had been received from various government offices, and he cited the war-production clinics now being sponsored jointly by AIEE Sections and other local groups as an aid to the war production. He called attention also to the special AIEE committee on co-operation with war agencies and to the many ways in which it had assisted (*EE, March '43, p. 119*). Subsections now are being formed within the territories of some AIEE Sections, especially those covering a large territory, to assist in maintaining attendance at Section meetings under wartime transportation restrictions. He mentioned also the special wartime services established for the benefit of the membership, and, as two examples, cited the quarterly news bulletin soon to be issued to AIEE members in the armed services and merchant marine, and the provisions which have been made to enable such men to maintain an inactive membership status, without payment of dues.

What the MVEA is doing to aid the war effort was outlined by Arthur L. Mullergren (M '19) president of that association. He first described briefly the organizational setup and membership of the association and the types of meetings held. The place of the utilities in the war effort has been the theme of MVEA meetings since Pearl Harbor, he declared. The intensified wartime activities in the midwest area have imposed particularly difficult problems on the power companies. Mr. Mullergren briefly described methods and measures which have been taken to cope with those problems. He emphasized the fact that all war-industry demands for electric power had been met, with minimum interference with nonwar activities.

In the fourth address of the session, AIEE President Harold S. Osborne spoke on "The Engineer and the War," discussing both the individual and professional responsibilities of the engineer in the war ef-

E. F. Mahood, AIEE vice-president of the South West District and chairman of the District meeting and Sections committees, stopped to converse with C. W. Nystrom, general outside plant engineer for Southwestern Bell Telephone Company, following one of the sessions of the AIEE South West District technical meeting. Mr. Nystrom spoke on "Conservation of Critical Materials in the Telephone Industry" at the meeting

fort. Full text of his address is presented elsewhere in this issue (*page 233*).

"Electrical Indicating Instruments in Wartime" was the subject of the concluding address, delivered by Harold L. Olesen (M '27) of the Weston Electrical Instrument Corporation, Newark, N. J. He briefly sketched the history of electrical instruments which he said originated in 1819. No new principles have been developed since 1883, he declared, but there have been great changes in the application of those principles, and the resultant instruments. He discussed the instruments required in the present war for aircraft, ship, and ordnance use, and characterized the requirements of instruments for ultra-high-frequency use in this war as totally unheard of previously. He indicated the magnitude of the present war requirements by stating that an average of one electrical instrument is required for every soldier. This means an output of from 12 to 15 times normal on the part of the instrument manufacturers. He depicted the present status of electrical instrumentation by striking contrasts and comparisons between the present war and World War I.

JOINT SESSION ON CRITICAL MATERIALS

Conservation of critical materials was the theme of the second session held jointly with MVEA during the AIEE South West District meeting. Five addresses on various phases of the subject were presented. AIEE Vice-President E. T. Mahood presided.

Analysis of Registration at Kansas City

Classification	Kansas City Section	District 7*	Other Districts	Totals
Members	98	65	54	217
Enrolled Students	55	24		79
Men guests	15	5	22	42
Totals	168	94	76	338

* Outside Kansas City.

Never before have we known a shortage of raw materials required for industrial manufacture in the United States, said H. M. MacDougal (A '40) of the War Production Board, Washington, D. C., discussing the functions and program of WPB. In citing some of the principal reasons for the present shortages, he drew comparisons and contrasts between World Wars I and II. He said that in World War I, only 94 pounds of metal were required per man, whereas in this war 4,900 pounds per man are required. Other important factors are the greater size of our armed forces now and the requirements of the lend-lease program. Of the four M's representing necessities in the present war-production program—men, machines, materials, movement—the most critical is materials. Substitutions and simplification of design are among the principal conservation measures advocated by WPB. Scrap no longer is considered a nuisance but a treasure; ordinary sources are becoming exhausted, however, and from now on scrap must be "dug" out of obsolete and unused equipment. Mr. MacDougal called attention to the salvage manual prepared some time ago for the power companies and said that a similar salvage manual is being prepared for all industry. In closing, he commended the power industry for its performance in the war effort.

At the AIEE South West District technical meeting: A. C. Monteith, chairman of the committee on power generation, who spoke on "Emergency Measures to Increase Output of Generating Equipment and Systems"; C. M. Laffoon, AIEE director and chairman of a subcommittee of the committee on power generation; and F. J. Meyer, AIEE director and vice-president in charge of operations for Oklahoma Gas and Electric Company, who spoke on "AIEE in the Southwest"

AIEE President Osborne in his address drew statistical comparisons between the amounts of critical metals available to the Axis countries and to the United Nations. The situation as indicated by these figures makes it imperative that we make the greatest possible use of what we have. He recommended the following six expedients to conserve critical metals: substitutions, redesign of products, restriction of plant addition to immediate needs only, standardization, salvage, and reduced inventories. (Full text of Doctor Osborne's address is scheduled for publication in a later issue.)

An address describing the AIEE wartime guides for the selection and operation of electrical equipment, prepared by J. R. North, chairman, AIEE standards committee (who was unable to be present), was read by A. C. Monteith, vice-chairman of that committee. The purpose of these guides is to assist users of electrical equipment to obtain the greatest possible utilization of such equipment under present emergency conditions. (A fuller description of the guides, their history, purpose, and status, is outlined in a separate item, *page 253*.)

Measures being taken by the telephone industry to conserve critical materials were outlined by C. W. Nystrom (M '33) of the Southwestern Bell Telephone Company, St. Louis, Mo. Substitutions, changes in design, and recovery of used materials, he cited as the three principal methods employed. He mentioned many specific instances of substitutions of less critical metals for more critical metals and quoted statistics as to the resultant savings. All used materials and equipment are salvaged, he said, and, whenever possible, reused. He also called attention to the increasing use of carrier communication. Mr. Nystrom said that in spite of wartime operating difficulties, in 1942 three quarters of a billion more telephone calls were handled throughout the system than in any previous year and that there had been a 45 per cent increase in tool traffic.

The last item on the session agenda was on emergency measures to increase output of generating equipment. This presentation constituted a preliminary report on a wartime guide for the operation of electric generating equipment which is being prepared by the AIEE committee on power generation and two of its subcommittees. A. C. Monteith, chairman of that committee, introduced the subject. Measures to increase output of generating equipment were reported by C. M. Laffoon, chairman of the subcommittee on that subject; and emergency measures to increase the output of generating systems, by R. L. Frisby, member of the committee on power generation. (An article summarizing the recommendations made in the final form of this guide is scheduled for publication in an early issue.)

STUDENT ACTIVITIES

In addition to the regularly scheduled events of the meeting, features of especial interest to students were held. These included: a student technical session; two breakfast gatherings, one for Branch officers, and the other for Branch counselors; and student consultations wherein student members could confer with representatives of various industries. H. F. Huffman (M '33) of the Southern Methodist University, Dallas, Tex., was elected District chairman of student activities for the ensuing year, to succeed W. F. Gray (A '38), current chairman.

Student Technical Session. Edward Ancona

of the University of New Mexico Branch presided at the student technical session. Four papers were presented by students from four Branches:

1. The Operation of Single-Phase Watt-Hour Meters, **Franklin Fansher**, University of Missouri, Columbia.

2. Revisions of the Electrical Code Due to the War Effort, **L. V. Randle**, Southern Methodist University, Dallas, Tex.

3. Routine Testing of Residential Watt-Hour Meters, **J. G. McDonald**, Kansas State College, Manhattan.

4. A Comparative Study of the Rationalized and Unrationalized MKS Unit Systems, **G. L. Johnson, V. J. McKale**, University of Kansas, Lawrence.

Student Consultations. Arrangements were made whereby students could confer with representatives of a variety of industries on conditions, prospects, and future outlook of those industries, Thursday morning, April 29. The following consultants were on hand, each in a separate room:

Aviation—Luther Hoffman, Transcontinental and Western Airways.

Communication—C. H. Weiser, Southwestern Bell Telephone Company.

Consulting Engineering—R. L. Baldwin (F '37) Burns and McDonnell Engineering Company, Kansas City.

Electrical Manufacturing—George Fiske (A '11) General Electric Company, Kansas City.

Power and Light Operating—G. O. Brown (A '15) Kansas City Power and Light Company.

Transportation—J. A. Parkinson, Atchison, Topeka and Santa Fe Railroad Company

LUNCHEON AND DINNER

Informal talks by national AIEE officers featured the luncheon held Thursday, April 29, during the Kansas City meeting. Students were admitted to the luncheon without charge, each student being assigned a senior member as host. C. G. Roush, chairman of the Kansas City Section presided. At the AIEE dinner Thursday evening, Tom Collins, formerly of Kansas City (now of Omaha, Neb.) and well-known midwest after-dinner speaker, talked on the subject "Ready or Not?" He presented refreshing viewpoints on the current situation. Vice-President E. T. Mahood acted as toastmaster at the dinner.

"The Engineer's Start in Civic Affairs" was the title of a talk prepared by P. L. Alger, chairman, AIEE technical program committee; in Mr. Alger's absence, his talk was read by S. M. DeCamp (M '24) of the General Electric Company, Kansas City. In this talk Mr. Alger suggested how the typical engineering graduate may proceed in seeking both the professional standing and the civic usefulness that accord with the high ideals of the engineering profession. After establishing a professional standing, the young engineer may apply himself to civic problems. The normal procedure for developing his civic standing is exactly similar to that followed in his professional development. However, any undue time or effort spent on pursuing a civic hobby at the expense of his professional work, Mr. Alger warned, will react very strongly against acceptance of his ideas on civic matters.

In the second talk, National Secretary H. H. Henline reviewed AIEE progress in recent years. He traced the fluctuations in membership since the early 30's, through the depression years and into the recovery period. AIEE membership now stands at its highest point in history—more than 20,000 members. Committee structure, Mr. Henline said, has been kept flexible in accordance with current requirements. He mentioned recent changes, consolidations, and new committees appointed. He reported that local, District, and national meetings are now geared very strongly to wartime requirements, in accordance with policies adopted last August. In an effort to assist as much as possible in the war effort, the Institute's board of directors decided to continue a full schedule of national and District technical meetings in spite of transportation difficulties. In conclusion, he said that the AIEE now is in a strong position and that there is every reason to expect it to continue so.

"AIEE in the Southwest" was the subject of the concluding talk at the luncheon, by F. J. Meyer, AIEE director, of Oklahoma City, Okla. Mr. Meyer discussed some of the current problems faced by engineers and engineering societies and their relationships to civic affairs.

SECTIONS CLINIC

Various phases of Section operation and management were discussed at the Sections clinic, and three recommendations to the District executive committee were passed. All Sections within the South West District were represented among the 35 members who attended. Also present were President Harold O. Osborne, National Secretary H. H. Henline, and Sections Committee Chairman E. T. Mahood. C. W. Mier, nominee for AIEE directorship, presided, and A. T. Campbell acted as secretary of the clinic.

The various types of meetings held by the different Sections represented were discussed in some detail. Some indicated a preference for relatively short meetings; others reported best results with dinner meetings. Some favored more joint activities with other local engineering groups, especially in matters of mutual interest such as civic activities. One Section reported that each member of its meetings and papers committee is made responsible for one meeting during the season; this has resulted in some excellent meetings and in the development of candidates for Section offices.

Mr. Mahood expressed the opinion that the general practice of sending incoming Section chairmen to the national summer meeting effectively promotes the welfare of the Institute, but that full advantage is not taken of the experience gained by outgoing Section officers. The ensuing discussion led to adoption of the recommendation that:

"It be made a part of the duties of the Section chairmen, at the close of their term of office to make a report in writing to the incoming officers, with copies to the District vice-president and the national secretary, covering the Section activities during the year and embodying recommendations for such changes, additions, or omissions in Section operation and management as their experience in office indicates would be beneficial to the Institute."

H. G. Mathewson, secretary of the North Texas Section, pointed out that many Section officers take office June 1, whereas national officers take office August 1. Material pertaining to Sections operations is sent to the new chairmen on the latter date. Mr. Mathewson suggested that such material be sent to Section officers as soon as they take office and suggested also that more complete instructions might help. The following recommendation grew out of the ensuing discussion:

"A pamphlet, to serve as a manual on Section operation and management, should be prepared and distributed to all newly elected Section officers by the national secretary upon notification of their election. This manual should cover all pertinent features of Section operation and management, duties of Section officers, and relevant parts of the constitution and bylaws."

The need of a clearinghouse for Section-meeting speakers also was discussed and various plans proposed. The discussion of this subject resulted in the recommendation that:

"It be made a part of the District secretary's duties to serve as a clearinghouse on speakers and programs to facilitate the exchange of information within the District as to the availability of speakers and programs or Section meetings."

President Harold S. Osborne spoke briefly regarding his travels among the Sections, declaring that "he was much impressed with the fact that the life of the Institute is in the Sections and that the future life of the Institute depends on them."

DISTRICT EXECUTIVE COMMITTEE MEETING

Award of District prizes for Student Branch papers, formation of subsections, recommendations passed by the Sections clinic, and the financial problems of Sections that are hosts to District or national meetings, were among the important items discussed at the meeting of the District executive committee. Vice-President E. T. Mahood presided, and District Secretary R. G. Kloeffler acted as secretary of the meeting.

Secretary Kloeffler presented a report covering certain aspects of the award of District prizes for student papers. His report and the ensuing discussion culminated in passage of the following motion:

1. The time of closure for submission of Student Branch papers for consideration for the District award shall be June 30.

2. It shall be the policy of the District to arrange for the judging of these papers as early as convenient after June 30 and to present the award early in the following fall.

3. In any year the granting of the award for the best Student Branch paper may be withheld if less than three papers be submitted or if the quality of the papers submitted be below normal. The decision concerning the quality of the papers is to rest with the judges.

Representatives of all Sections in the District reported that careful consideration had been given to the possibility of forming subsections. All but two Sections reported that subsections do not seem to be desirable. S. C. Commander, secretary of the Houston (Tex.) Section, reported that speakers at meetings in Houston sometimes repeat their talks at additional meetings in Beaumont. F. A. Decker, chairman of the New

Mexico–West Texas Section, reported that Albuquerque is 300 miles from Section headquarters and that it needs a subsection.

Action was taken providing for the establishment of a District fund to assist host Sections in financing District and national meetings. To start the fund, the Kansas City Section agreed to turn over any funds remaining from the special collection made to finance the current District meeting. The plan calls for contributions from the Sections at the rate of 25 cents per member annually. The District secretary will act as custodian, and payments from the fund are to be made only with the approval of the chairman of the Section holding a District or national meeting, the District secretary, and the District vice-president. Final approval of the plan rests with the executive committees of the Sections.

Three recommendations made at the clinic on Section operations and management (reported separately) were adopted by the District executive committee. The recommendation pertaining to the preparation of a manual on Section operation and management is to be referred to the committee on Sections by Vice-President Mahood, who is chairman of that committee.

A proposal to hold the next District meeting at San Antonio, Tex., was discussed informally, and tentatively approved.

COMMITTEES

E. T. Mahood, vice-president representing the South West District, was chairman of the meeting committee. Other members were A. T. Campbell, P. C. Ellis, W. F. Gray (District chairman of student activities), R. G. Kloeffler (secretary, South West District), I. T. Monseth (chairman, St. Louis Section), Ralph Randall (chairman, Oklahoma City Section), C. G. Roush (chairman, Kansas City Section), P. H. Underwood (chairman, Houston Section), and C. V. Waddington.

Subcommittee chairmen were as follows:

Meetings and Papers—V. P. Hessler.
Student Activities—R. L. Baldwin.
Inspection Trips—A. E. Betts.
Publicity and Attendance—A. T. Campbell.
Finance—George Fiske.
Hotels and Registration—C. G. Roush.
Luncheons and Dinners—P. C. Ellis.

Four Technical Sessions Held at Kansas City Meeting

Sessions on electrical machinery, communication, transportation, and selected topics comprised the technical program of the recent South West District meeting in Kansas City, Mo. Conservation of materials, emergency loading and utilization of electrical equipment, teaching of wartime subjects, and special practices developed to meet wartime needs were among the most important subjects discussed.

ELECTRICAL MACHINERY

Design and construction features of the Oilostatic transmission system and its applications were described by Charles E. Bennett (F '25) of the Okonite-Callender Cable Company, Inc., Paterson, N. J. This system consists of one or more paper-insulated cables installed in a steel pipe which is filled with insulating oil under high pressure. Mr. Bennett presented operating data on the first system, which was installed in 1932 on a 66-kv line, and which, he said, had operated successfully. Satisfactory operation was reported on other installations ranging in voltage up to 132 kv. Ten years' experience in handling and installing nonleaded paper cables in steel pipes has demonstrated that this is not injurious to the cable.

There is no safe overload rule for utilizing the latent emergency capacities of transformers, said J. K. Hodnette (F '42) of the Westinghouse Electric and Manufacturing Company, Sharon, Pa., who spoke on conservation of critical materials in transformers. However, he described a simple thermoelectric relay, the thermal characteristics of which match those of the ordinary transformer. He also described the use of Hipersil, an improved silicon steel for transformer cores. The use of this material results in a transformer of smaller physical dimensions which means the saving of materials in all parts of the unit; the average saving is said to be 20 per cent as compared with transformers using ordinary silicon steel. With regard to transformers already in service, Mr. Hodnette pointed out that air-blast cooling and provisions for circulating the oil within the transformer tank would each increase the rating of a power transformer by one third. By utilizing both these expedients, 45 per cent less materials are required for a given transformer output.

A paper "Effect of Control on the Characteristics of D-C Series and Shunt Motors," presented by A. A. Merrill of the General Electric Company, Schenectady, N. Y., showed how the characteristics of these motors may be "twisted" into almost every desirable form by simple manipulation of external resistors and connections. Mr. Merrill presented many charts showing the speed-torque relationships for a variety of types of control connections and explained their application to specific problems.

"Normal and Emergency Loading of Power Transformers," by H. B. Keath (F '39) and W. L. J. F. Godin of the Wagner Electric Corporation, St. Louis, Mo., was presented by Mr. Godin. In this paper the authors endeavored to unify and to bring up to present-day practice the different viewpoints on this subject. They contended that all groups and subdivisions of transformers can be brought back to the fundamental case of the 55-degree-centigrade-rise self-cooled transformer and that the various groups differ only in their external features—that is, in the method of cooling and conditions of loading. This simplifies the procedure of determining emergency overloads. Standardized rules for normal loading or loading for normal life expectancy simply become functions of the average daily ambient temperatures, the authors concluded.

"Graphic Solutions in Unbalanced Transformer Loading," by R. H. Jones, Jr. (A '41) of the Moloney Electric Company, St. Louis, Mo., was presented by W. C. Wooley (Mr. Jones is now on active duty as a lieutenant in the United States Naval Reserve). This paper outlined the development and application of several graphical constructions in the solution of problems in unbalanced transformer loading.

O. T. Farry (M '40) of the Wagner Electric Corporation, St. Louis, Mo., presided at this session.

COMMUNICATION

The session on communication began with a paper on wartime courses in ultra-high-frequency techniques, by R. E. Galbraith (A '38) of the University of Texas, Austin. He said that it had been found necessary to give not just training in ultrahigh-frequency work but complete training in radio, because the majority of students had had no previous radio training. The course, which requires 16 weeks for completion, is divided into four parts:

1. Smoothing circuits.
2. Transients.
3. Antennas and wave guides.
4. Negative-grid tubes.

He said that in the beginning no textbooks nor laboratory apparatus were available; consequently, special "class notes" had to be prepared and makeshift apparatus pieced together out of parts collected from a variety of sources. In the discussion of this paper it was pointed out that the expanding applications of ultrahigh frequencies will require a change in the method of teaching the fundamentals of electrical transmission.

The paper, "Train Communications," by L. O. Grondahl (M '42) and P. N. Bossart of the Union Switch and Signal Company, Swissvale, Pa., was presented by G. A. Richardson (A '42) of the University of Kansas, Lawrence. The paper describes a carrier system for communicating between railway vehicles and between such vehicles and fixed points. (This paper is scheduled for publication in the July *Transactions* section.)

Communication facilities provided for civilian-defense purposes were described by O. S. McDaniel of the Southwestern Bell Telephone Company, Dallas, Tex. He described:

1. The aircraft warning system whereby information on airplanes is communicated to Army authorities.
2. The air-raid warning system whereby the Army communicates its instructions to the air-raid wardens.
3. The provisions enabling the wardens to transmit information to the public and to summon any required services.

He described the so-called conference system whereby from 10 to 20 telephone calls may be made simultaneously, thus facilitating the sending out of warnings to danger areas. He also mentioned the war emergency radio service established for local communication when other means fail (*EE, May, '43, p. 224*).

The final paper of the session, by G. A. Dyer (M '39) of the Southwestern Bell Telephone Company, Dallas, Tex., described the recently installed Dallas–San Antonio intercity toll cable. Mr. Dyer first traced the fluctuations in telephone traffic on his company's system from the late 20's, through the depression years, and into the present period of intensified activity. Extensive use of carrier of the so-called "J" and later the "K" types have assisted materially in meeting wartime demands for increased communication facilities. Mr. Dyer then described the twin cables installed between the two cities and told how the cables were buried in the ground and covered, all in one continuous operation, by a special plow train. His oral presentation was supplemented by a motion picture showing the operation of the plow train and some of the many obstacles encountered on the right of way.

H. R. Fritz (F '39) Southwestern Bell Telephone Company, St. Louis, Mo., presided at the communication session.

TRANSPORTATION

Operating experiences with modern rapid-transit equipment was the general subject of four papers presented at the transportation session. I. T. Monseth (M '39), Westinghouse Electric and Manufacturing Company, St. Louis, Mo., presided.

The advantages of high-speed traction motors were discussed by C. A. Atwell (A '41), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in the first paper. (This paper is scheduled for publication in the July *Transactions* section.)

Although we are now engaged primarily in a war of production of materials and transportation of men and materials to the scene of the fighting, of almost equal importance is the transportation of workers between their homes and the plants producing war materials, said G. M. Woods, Westinghouse Electric and Manufacturing Company, in his paper "Maximum Utilization of Transit Equipment." He outlined methods in use by rapid-transit companies in handling the unprecedented increase in traffic brought about by the war. Some of the expedients discussed are: rehabilitation of retired cars; puchase of second-hand cars, previously released from abandoned routes; restoration of streetcar service where tracks still exist; improvement of scheduling; and purchase of new cars where extreme need can be shown. Other at least equally important steps, he said, rest with the communities themselves. Among these are staggering hours, reducing number of stops, and facilitating the movement of mass-transportation vehicles by giving them preference in traffic regulation.

Kansas City's wartime experiences and practices in mass transportation were described in a paper by L. L. Davis (M '36) and G. H. Frieling, of the Kansas City Public Service Company, presented by Mr. Davis. Riding in Kansas City for the six months prior to March 1, 1943, increased 75 per cent over the corresponding period prior to March 1, 1941, he said. To date it has been possible to supply the increased demand. Vehicles that formerly were operated with partial loads absorbed much of this increase. Old discarded equipment has been rehabilitated and placed in service. The changes instituted by the Office of Defense Transportation have added an equivalent 289 vehicles to the fleet and saved an estimated 2,961,215 vehicle-miles per year, Mr. Davis added. He mentioned the splendid co-operative spirit of the public and the additional burden on maintenance facilities.

In the final paper, F. Norman Hill of the St. Joseph (Mo.) Railway, Light, Heat, and Power Company, summarized 11 years' operating experience with trolley coaches. He presented some interesting comparisons between trolley and motor coaches. The trolley coach is approximately 15 per cent faster because of its better accelerating characteristics, and its negotiating grades more easily. The trolley coach has a higher first cost, but lower operating and maintenance costs and longer life. Public reaction favors the trolley coach, as reflected by traffic increases.

SELECTED TOPICS

Five papers on many different subjects were presented at the selected-topics session at which G. T. Shoemaker (F '39), Kansas City Power and Light Company, presided.

G. C. Quinn, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., reviewed wartime trends in arc welding. Although arc welding has been used for many years in maintenance and repair work, only recently has it been applied to production. Although it started slowly, the increase in application during the current war period has been tremendous. To illustrate, Mr. Quinn said that $18,000,000 were spent on arc welding in 1938, but in 1942 the expenditure for the year had risen to $128,000,000. He reviewed the progress in welding techniques, electrodes, and machines. Standard techniques are needed, he said, and this problem is only halfway solved. Electrodes, which were poor at the beginning, have been improved vastly, and small percentages of alloying elements are now being added to the rod coatings. He predicted further improvement and standardization of welding rods. In regard to equipment, he said that d-c motor-generator sets had been developed highly and had not been changed much in recent years. Electronic welders are proving best for thin materials. Transformer welders were initially unsatisfactory, and many operated at too high voltages; with the introduction of coated electrodes, these voltages were reduced. A-c welders giving continuously variable output current later were developed; today a-c welders comprise a large part of new equipment installations.

One of the few safety engineering courses in the United States was described by A. Naeter (M '30), Oklahoma Agricultural and Mechanical College, Stillwater. The course consists of three parts:

1. Physiology and industrial hygiene.
2. Safety engineering and accident prevention.
3. First aid.

Lectures are given by men engaged in actual safety work and also by faculty members. First-aid instruction is given by a representative of either the Bureau of Mines or of the Red Cross. The instruction is supplemented by practical hints for safe working procedures.

The third paper of this session, by G. F. Leland and L. T. Rader (A '34) of the General Electric Company, Schenectady, N. Y., presented a mathematical analysis of dynamic braking of a d-c shunt motor and its load. (This paper is scheduled for publication in the July *Transactions* section.)

Amplidyne circuits were described and performance characteristics analyzed in the fourth paper, by F. E. Crever (A '27) of the General Electric Company, Schenectady, N. Y.

Inductive heating in ferrous-metal equipment members adjacent or in close proximity to conductors in switchgear was the subject of the final paper, presented by Stanley C. Killian (A '42) Delta-Star Electric Company, Chicago, Ill. With the present emphasis on conservation of copper and other nonferrous metals, it is important that the less critical metals be used wherever possible for fittings and enclosures. Mr. Killian summed up the data presented in his paper in the following approximate manner:

"Up to 600 amperes, little precaution needs to be taken against magnetic heating, and steel parts can be used almost indiscriminately. From 600 to 3,000 amperes, the problem must be given careful consideration, and nonferrous parts must be used in conjunction with ferrous parts. Above 3,000 amperes, all parts should be nonferrous."

Membership Passes 20,000 Mark

Institute Members:

The Institute has crossed the 20,000 mark in membership. This accomplishment has, in large measure, been due to the co-operation which we have received from individual members. The names which many of you have suggested have given us a substantial base upon which to build. We want you to know that this effort on your part is appreciated.

(*Signed*) JOHN H. PILKINGTON
Chairman, National Membership Committee

Section and Branch Activities—Annual Report for 1942-43

The following constitutes the annual report on Institute Section and Branch activities for the fiscal year which ended April 30, 1943. Similar information for three preceding fiscal years appeared in *Electrical Engineering* in June 1942, pages 322–3; June 1941, pages 285–7; June 1940, pages 250–3.

Present members of the Sections committee and the committee on Student Branches, which supervise the divisions of Institute activities covered by this report, are:

Sections—E. T. Mahood, chairman; J. M. Thomson, vice-chairman; E. W. Schilling, secretary; O. C. Brill, M. S. Coover, C. A. Faust, H. L. Hazen, S. J. Lisberger, W. B. Morton, R. M. Pfalzgraff, and ex officio the chairmen of all Sections of the Institute.

Branches—R. G. Warner, chairman; E. W. O'Brien, vice-chairman; H. W. Bibber, L. A. Bingham, P. L. Hoover, Everett S. Lee, W. J. Miller, A. Naeter, B. L. Robertson, G. H. Sechrist, V. G. Smith, E. M. Strong, G. W. Swenson, and ex officio all Student Branch counselors.

Table I. Section Membership and Meetings During Year Ending April 30, 1943

Section	AIEE Members August 1941	AIEE Members August 1942	Number of Meetings	Average Attendance
Akron	87	94	8	67
Alabama	45	44	2	17
Arizona	28	37	8	29
Boston	439	516	8	220
Central Indiana	144	133	9	213
Chicago	810	836	6	239
Power group			4	64
Industrial group			3	69
Communication group			3	97
Cincinnati	212	214	6	134
Dayton Subsection			1	
Cleveland	363	376	4	
Technical group			1	74
Columbus	86	95	5	328
Zanesville Subsection				
Connecticut	299	333	5	81
Denver	177	180	8	62
East Tennessee	137	145	14	232
Erie	56	65	6	60
Florida	100	111	1	12
Fort Wayne	80	93	9	65
Georgia	122	119	3	138
Houston	141	133	9	66
Iowa	81	84	11	98
Ithaca	55	53	4	53
Kansas City	128	140	9	130
Lehigh Valley	194	188	6	97
Los Angeles	507	540	11	192
Aviation division			1	
Louisville	86	73	9	87
Lynn	167	186	8	375
Madison	72	73	5	62
Rock River Valley Subsection			8	77
Mansfield	77	71	8	43
Maryland	286	322	8	104
Memphis	66	56	9	29
Mexico	57	53	7	38
Michigan	398	418	9	125
Round table meetings			2	
Milwaukee	286	313	10	155
Minnesota	103	98	10	53
Power group meetings			3	52
Montana	40	45	5	27
Montreal			1	38
Muscle Shoals	30	33	7	20
Nebraska	45	59	5	53
New Mexico–West Texas	43	43	8	17
New Orleans	132	133	9	39
New York	3,492	3,447	4	338
Power group			5	211
Communication group			2	95
Transportation group			2	135
Illumination group			3	178
Basic science group			4	93
Niagara Frontier	207	198	8	60
Niagara Falls Subsection			1	
North Carolina	101	107	1	68
North Texas	181	170	8	77
Oklahoma City	117	104	10	88
Philadelphia	750	809	11	207
Instruments and measurements discussion group			2	140
Communication discussion group			3	85
Industrial practice discussion group			2	41
Power discussion group			4	81
Foremen's discussion group			1	42
Pittsburgh	630	662	11	148
Pittsfield	197	194	6	771
Popular lectures			6	
Portland	196	196	10	71
Transmission and distribution committee			2	50
Providence	95	100	8	43
Rochester	110	112	11	90
St. Louis	304	360	9	102
San Diego	46	54	8	41
San Francisco	543	549	9	138
Saskatchewan	10	8	1	
Schenectady	484	559	7	193
Seattle	202	230	9	82
Sharon	120	153	9	67
South Bend	52	58	10	58
South Carolina	50	53	2	54
South Texas	48	53	6	31
Spokane	84	82	9	46
Springfield	51	52	9	81
Syracuse	103	119	7	79
Toledo	80	89	9	60
Toronto	363	396	14	153
Tulsa	90	87	8	46
Urbana	68	78	6	112
Illinois Valley Subsection, Peoria				
Utah	72	64	9	45
Vancouver	91	95	9	67
Virginia	137	150		
Washington	491	600	9	219
West Virginia	54	39	1	200
Wichita	64	57	10	42
Worcester	65	63	7	97
Total Sections 73	15,927	16,652	598	

Total attendance, 66,111

Table II. Branch Meetings Held During Year Ending April 30, 1943

Branch	Number	Average Attendance
Akron, University of	6	10
Alabama, Polytechnic Institute	5	50
Alabama, University of	7	19
Alberta, University of	5	23
Arizona, University of	29	14
Arkansas, University of	9	14
British Columbia, University of	17	21
Brooklyn, Polytechnic Institute of		
Day division	6	23
Evening division	6	12
Brown University	3	17
Bucknell University	4	25
California, Institute of Technology	5	38
California, University of	4	41
Carnegie Institute of Technology	25	69
Case School of Applied Science	5	29
Catholic University of America	2	21
Cincinnati, University of	10	27
Clarkson College of Technology	4	20
Clemson Agricultural College	5	27
Colorado State College	4	17
Colorado, University of	8	35
Columbia University	4	30
Connecticut, University of	3	28
Cooper Union		
Day division	6	29
Evening division		
Cornell University	3	56
Delaware, University of	4	23
Denver, University of	7	25
Detroit, University of	6	31
Drexel Institute of Technology	12	24
Duke University	7	21
Florida, University of	9	20
George Washington University	11	23
Georgia School of Technology		
Harvard University		
Idaho, University of	14	55
Illinois Institute of Technology	2	46
Illinois, University of	1	440
Iowa State College	8	52
Iowa, University of	33	23
Johns Hopkins University	2	31
Kansas State College	12	72
Kansas, University of	8	34
Kentucky, University of	20	98
Lafayette College	4	17
Lehigh University	1	60
Louisiana State University	7	22
Louisville, University of	7	19
Maine, University of	2	16
Manhattan College	4	25
Marquette University		
Maryland, University of	7	19
Massachusetts Institute of Technology		
Michigan College of Mining and Technology	12	34
Michigan State College	8	27
Michigan, University of	9	29
Milwaukee School of Engineering	3	44
Minnesota, University of	5	26
Mississippi State College	7	23
Missouri School of Mines and Metallurgy	3	28
Missouri, University of	5	46
Montana State College	10	27
Nebraska, University of	13	40
Nevada, University of	8	22
Newark College of Engineering	5	47
New Hampshire, University of	10	25
New Mexico State College	5	30
New Mexico, University of	11	28
New York, College of the City of		
Day division	16	71
Evening division		

Table II (continued). Branch Meetings Held During Year Ending April 30, 1943

Branch	Number	Average Attendance
New York University		
Day division	4	38
Evening division	3	27
North Carolina State College	11	33
North Dakota Agricultural College		
North Dakota, University of	4	15
Northeastern University	7	48
Northwestern University	1	55
Norwich University	4	18
Notre Dame, University of	8	19
Ohio Northern University	14	21
Ohio State University	12	33
Ohio University	2	23
Oklahoma Agricultural and Mechanical College	8	32
Oklahoma, University of	7	24
Oregon State College	5	30
Pennsylvania State College	6	125
Pennsylvania, University of	4	21
Pittsburgh, University of	43	72
Puerto Rico, University of	1	30
Pratt Institute	16	33
Princeton University	3	
Purdue University	6	76
Rensselaer Polytechnic Institute	8	46
Rhode Island State College	2	14
Rice Institute	9	26
Rose Polytechnic Institute	10	31
Rutgers University	4	16
Santa Clara, University of	11	21
South Carolina, University of	13	20
South Dakota State College	9	21
South Dakota State School of Mines	8	27
Southern California, University of	7	41
Southern Methodist University	9	28
Stanford University	6	27
Stevens Institute of Technology		
Swarthmore College		
Syracuse University		
Tennessee, University of	13	22
Texas Agricultural and Mechanical College	3	39
Texas Technological College	9	29
Texas, University of	9	41
Tufts College	8	32
Tulane University	8	23
Union College	8	30
Utah, University of	6	26
Vanderbilt University		
Vermont, University of	20	24
Villanova College	8	9
Virginia Military Institute	2	44
Virginia Polytechnic Institute	28	42
Virginia, University of	5	13
Washington, State College of	13	32
Washington, University of	8	47
Washington University	4	25
West Virginia University	5	29
Wisconsin, University of	6	30
Worcester Polytechnic Institute	3	68
Wyoming, University of	4	18
Yale University	4	58
Total—125 Branches		

Table III. Section Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1941	1942	1943
Number of Sections	72	72	73
Number of meetings held	703	647	598
Average number of meetings	9.8	9.0	8.2
Total attendance	92,554	78,254	66,111
Average attendance per meeting	132	121	112

Table IV. Branch Meetings Held During Last Three Fiscal Years

	For Year Ending April 30		
	1941	1942	1943
Number of Branches	123	124	125
Number of meetings held	1,163	946	942
Average number of meetings	9.5	7.6	7.5
Total attendance	52,285	37,785	38,227
Average attendance per meeting	45.0	39.9	40.6

Table V. Conferences on Student Activities

District	Location	Date
5	Northwestern University, Evanston, Ill.	5/2/42
8 and 9, University of British Columbia	Vancouver, B. C., Canada (Pacific Coast convention)	9/9–11/42
2	University of Pittsburgh, Pittsburgh, Pa.	10/16/42
7	Kansas City, Mo. (South West District meeting)	4/28/43

Table VI. Section or Joint Section and Branch Meetings With Active Student Participation

Sections	Branches	Date	Student Talks	Attendance
Maryland	Johns Hopkins University	5/4/42	3	90
Lehigh Valley	Lafayette College, Lehigh University	5/8/42	1	82
Oklahoma City	University of Oklahoma	5/13/42	2	94
Portland	Oregon State College	5/16/42	3	67
South Bend	University of Notre Dame	12/8/42	4	32
South Texas	University of Texas	12/14/42	5	45
Akron	University of Akron	1/12/43	5	46
Vancouver	Univ. of British Columbia	2/16/43	4	65
Houston	A. & M. College of Texas, Rice Institute	3/22/43	5	80
Cincinnati	University of Cincinnati	4/1/43	4	153
Oklahoma City	University of Oklahoma	4/7/43	2	65
Iowa	University of Iowa	4/15/43	8	31
New Orleans	Tulane University	4/16/43	2	54
Totals—13 Sections, 14 Branches, 13 meetings			48	884

Nebraska Student Branch Passes 50-Year Mark

The University of Nebraska AIEE Student Branch founded in 1893 as the Electrical Engineers Society celebrated its 50th anniversary May 5, with a dinner at the Lincoln (Nebr.) YWCA. Reminiscences of the original society's activities by former members keynoted the meeting.

In 1907 the older society received Branch standing in AIEE. The Nebraskans recalled that three former AIEE presidents have come from their ranks: Bion J. Arnold, president 1903–04; Dugald C. Jackson, president 1910–11; and Harris J. Ryan, president 1923–24. J. G. White, founder of the New York engineering firm and AIEE vice-president from 1907 to 1909, was also an early member.

The celebrants were reminded of the origin of a Branch custom which has persisted in the college's "Engineers' Night" ceremonies. Under the spell of the 1893 World's Fair at Chicago, Ill., R. B. Owens established in 1895 an annual show of the latest electrical developments. To the electrically naive public of the 1890's it held many of the elements of a sideshow. Demonstrations of the electric welding machine, the water-pail forge, the glowing Crooke's tubes, the silver plating of pennies, the electrolytic decomposition of water, the traveling "electric-light man" with bulbs fastened to his clothing, the arc furnaces, and the operation of dynamos, arc lamps, and other equipment were on the first program. K. C. Randall (M '12) was listed as "director of exhibits." One of the two Edison bipolar generators which Professor Owens brought back from the Chicago fair is now in the Ford museum at Dearborn, Mich.

Evidence that the present members are keeping the high standards set by their predecessors lies in the fact that three of the last five annual prizes for the best student paper in the North Central District have been awarded the Nebraska Branch.

A paper, "Effect on Telephone Circuits of Induction Motor Harmonics," presented by I. M. Ellestad (A '24), and a short history of the Branch culled from the early minutes of the society, presented by a student completed the anniversary program. Congratulatory telegrams were received from H. S. Osborne, AIEE president, and A. L. Jones, AIEE vice-president for the North Central District. L. A. Bingham, nominee for the North Central District vice-presidency, is Branch counselor.

Schenectady Section Organizes New York Production Clinic

Following the expressed proposal of the War Production Board that managers, plant engineers, production men, shop superintendents, and foremen give others the benefit of their production experience to foster more intense development of our resources for total war, the Schenectady Section initiated a Northeastern New York War Production Conference jointly spon-

sored by the engineering societies of the region. The one-day conference was held April 15 at the Hotel Van Curler, Schenectady.

The main work of the meeting was conducted in two groups of four panel sessions held at 4 p.m. and 8 p.m., respectively. Each session was sponsored by the engineering society most interested in the problem under consideration.

The afternoon sessions discussed: operating problems and maintenance, sponsored by the New York State Society of Professional Engineers; employment, training, and women in industry, arranged by the American Society of Mechanical Engineers; metallurgy and materials substitution, under the sponsorship of the American Society for Metals; and, electric power supply, sponsored by AIEE.

Evening panels were: electric motor and control problems, led by AIEE; inspection and quality control, arranged by ASME; welding, organized by the American Welding Society; and, corrosion and metal protection, under the leadership of the American Chemical Society.

To solve any individual problems confronting those attending the conference a special professional board for consultation was set up. The board of specialists, composed of members of the Schenectady works laboratory, General Electric Company, was prepared to give advice in the fields of metals and die casting, forgings, paints and varnishes, fusion welding, metallography and X ray, chemistry, die and tool steels, metallurgy, resistance welding, refractories, foundry, lubricants, brazing and soldering, and cutting tools.

At the general meeting which opened the conference at 2:00 p.m., addresses by Colonel J. L. Walsh of the Army Ordnance Association, and L. A. Umansky (M '27) of the industrial engineering department of the General Electric Company, were featured. J. C. Page (A '41), conference chairman, presided. An address, "Education for Management" by Harold V. Coes, ASME president, was the main event of the dinner held at 6:30 p.m. T. M. Linville (M '34), chairman AIEE Schenectady Section presided.

Other engineering societies which cooperated in planning the conference were: American Society of Tool Engineers, the Society of Engineers of Eastern New York, the Society of Automotive Engineers, the American Society of Civil Engineers, and the Albany (N. Y.) Society of Engineers.

1943 Lamme Medal Nominations Due December 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the AIEE Lamme Medal, to be awarded early in 1944, may be submitted by any member in accordance with section 1 of article VI of the bylaws of the Lamme Medal committee, as quoted in the following:

The committee shall cause to be published in one or more issues of *Electrical Engineering*, or of its successors, each year, preferably including the June issue, a statement regarding the "Lamme Medal" and an invitation for any member to present to the national secretary of the Institute by December 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least three engineers of standing, who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee to enable the committee to determine its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specific information should be given regarding his individual contributions. Names of endorsers should be given as specified in the foregoing quotation.

STANDARDS • • •

Revision of Marine Rules for War Emergency Now Available

The AIEE committee on marine transportation at the request of the War Production Board has reviewed "Recommended Practice for Electrical Installations on Shipboard (AIEE Standard 45)." As a result of this review there has been developed a modification of and Supplement to Standard 45. These modifications are issued solely for the purpose of conserving critical materials. The use of the modifications will result in a shipboard electrical installation of a lower standard than is contemplated by the regular standard but, in view of the present emergency, is considered satisfactory for the purpose intended. The modification of Standard 45 must be used in conjunction with that pamphlet. Copies of the new publication, known as "45A—Modification of and Supplement to Recommended Practice for Electrical Installations on Shipboard," are now available at a cost of 50 cents each with the usual discount of 50 per cent to AIEE members on single copies. Copies may be procured from AIEE headquarters, 33 West 39 Street, New York, N. Y.

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE national technical meeting, Cleveland, Ohio, June 21–25, 1943, and are expected to be ready for distribution in advance pamphlet form within the current month. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Automatic Stations

43-84—Interim Report on Application and Operation of Automatic-Reclosing Equipment on Stub Feeders; *AIEE subcommittee on a-c automatic reclosing equipment. 20 cents.* This report presents the results of a survey which has been made to obtain data on typical present-day a-c automatic-reclosing equipment and practices as applied to stub feeders having a single end source of power. The data received provide a good summary of the reclosing practices in general use and the performance being obtained. They also give an indication of the possibilities of using immediate initial reclosure more extensively for some types of loads. This subject is of timely interest because of the possibilities of conserving critical materials in such cases where the application of automatic-reclosing equipment will defer the necessity of providing additional circuit facilities.

43-101—Interim Report on Characteristics and Performance of Conductors for Supervisory Control and Telemetering; *AIEE subcommittee on characteristics and performance of conductors for supervisory control and telemetering. 25 cents.* The report summarizes data covering 189 circuits totaling about 1,200 circuit-miles and about 9,000 circuit-mile-years. Whereas the amount of data may not be adequate to represent completely the practices and experiences with respect to conductors used for supervisory control and telemetering, certain generalizations seem permissible. The indications are that

1. About 15 per cent of the circuits are over ten miles (route) in length.
2. Slightly over half are privately owned.
3. Less than 15 per cent have any open-wire construction.
4. Only about ten per cent use a ground-return path.

It is indicated that the pilot conductors account for out-of-service time less than 1/20 of one per cent of the total time. The differences between the performance of privately owned and leased circuits are not large; the performance of both types of conductors is good, and continued improvement is indicated. Pilot conductors in cable, with automatic supervision and with properly designed and co-ordinated terminal protection, seem to be preferred in future installations.

43-86—Experience With Oil Circuit Reclosers on REA Systems; *Lee M. Moore (M '40), Bruce O. Watkins (A '43). 20 cents.* For three years surveys have been made of the operation of small single-pole automatic-reclosing oil circuit breakers (also called "oil circuit reclosers" and "service restorers") on rural electric distribution systems financed by the Rural

Future AIEE Meetings

National Technical Meeting
Cleveland, Ohio, June 21–25, 1943

National Technical Meeting
Salt Lake City, Utah, September 2–4, 1943

Southern District Meeting
Roanoke, Va., November 16–18, 1943

Electrification Administration. Results of these surveys indicate that the ratio of lockouts to operations is less than five per cent in most cases, and that there are from four to nine operations per month per breaker during the spring and summer, with each breaker controlling about 20 miles of line. The number of breaker failures and other breaker difficulties have been a small percentage of the total number of breakers installed. These surveys, together with discussions with system managers, have indicated that automatic-reclosing breakers offer many advantages for rural line sectionalizing. Presently available breakers can be much improved in operating characteristics, and new sectionalizing devices are needed. The paper presents suggestions for such improvements.

Basic Sciences

43-106—Formulas for Calculating Short-Circuit Forces Between Conductors of Structural Shape; *Thomas James Higgins (A '40). 25 cents.* The general theory essential to calculation of the short-circuit electromagnetic force exerted between two long parallel conductors with cross sections comprised of arbitrary configurations of parallel-sided rectangular areas is developed through use of basic electromagnetic principles. Application of this theory encompasses that already developed for the special cases of two conductors having coplanar axes and identical parallel-sided rectangular or hollow rectangular cross sections. It affords calculation of the short-circuit electromagnetic forces exerted among the conductors of any d-c single-phase or polyphase bus comprised of conductors of structural shape (rectangular straps, rectangular tubing, channels, angles, tees, *I* beams, and the like), a category not *generally* treated hitherto in the literature, though the shapes just mentioned and others are now in common use. Corroborative of the general theory and illustrative of application of it, specific formulas are obtained for the electromagnetic force exerted between the symmetrically located conductors of a single-phase bus comprised of two straps and two channels back-to-back. The principal literature on calculation of the short-circuit forces exerted on bus supports is mentioned in the paper.

43-107—A Method for Determining the Normal Modes of Foster's Reactance Networks; *Wilbur Reed LePage (A '34). 15 cents.* A Foster reactance network may be a series combination of antiresonant circuits or a parallel combination of resonant circuits. The zeros of the impedance function of the former or of the admittance function of the latter are the normal modes for their respective voltage or current excitation. The function is written in the partial-fraction form, and all but two of the terms are replaced by constants which are determined from a knowledge of an upper (or lower) bound of the required zero. The resultant expression may be solved for zero, as a quadratic, to give a new lower (or upper) bound, respectively. Continued application of this process gives two sequences, converging on the zero from above and below. There is a zero between each pair of poles; and, since these are known from the network structure, they may be used as the bounds of the zero, in the initial application of the process.

43-108—A Method for Correlating Duty-Cycle Tests on Solenoids; *J. E. Ryan. 15 cents.* A method is presented by which a relatively small amount of test data can be correlated and used to predict the steady temperature rise of a particular solenoid when the latter is operating cyclically with any combination of load, stroke, and timing. Although it has been used chiefly for a-c solenoids, the method is applicable to any device which has a cycling period substantially less than its thermal time constant.

Civic Affairs

43-122-ACO—The Engineer's Interest in City Planning; *F. A. Cowan (M '29). 20 cents.* A report of the conference on City and Regional Planning at the Northeastern District meeting, Pittsfield, Mass., April 8, is to be made available at the summer meeting. The report includes a résumé of the principal addresses and discussions by a number of civic officials and experts who are active in planning work. The conference covered such topics as the relation of industrial research to regional development and city planning and the role of planning in a world at war with special attention to the problems of the postwar period. Throughout the discussions emphasis was placed on the contributions the engineer can make to planning programs and on the advantages of organizing the efforts of the engineers along these lines to make the most effective use of their knowledge and training. The necessity for a full appreciation by the engineers of the problems of financing civic improvements and obtaining the co-operation and approval of the public was also stressed. The report closes with a summary of the conclusions of the conference and suggestions regarding the future interest of engineers in city planning as an aid in formulating their long-range engineering programs.

Communication

43-120—Subcenter Switching Systems for Teleprinter Tie Lines; *F. L. Currie. 20 cents.* One of the means used by the telegraph companies for improving the speed of their service is the provision of printing telegraph circuits between their central offices and the offices of many users of the telegraph. In the beginning, circuits of that type were restricted to patrons whose volume of telegraph business and proximity to a central office justified the expense involved in their installation and maintenance. A large part of that expense, when the patrons are located remotely from the central office, is in the line wire costs. This paper describes an automatic-switching means which economically enables a large number of patrons, when grouped in one locality, to be furnished printing telegraph service with a distant central office by causing them to share the use of a comparatively small number of line wires between that locality and the distant central office. The paper also cites benefits gained from present installations.

Electric Welding

43-121—Automatic Voltage Compensator for Resistance-Welding Control; *E. M. Callender (A '35), R. S. Phair (A '34). 20 cents.* The paper describes a simple electronic device that has been developed and used successfully to regulate the welding current under adverse line regulation. Line feeders are being overloaded heavily, and additional copper is often unavailable in this wartime emergency. The device, therefore, has special significance at this time. Circuits and general discussion of the welder control and the compensator are given. Numerical testing data are also given to show the importance of maintaining uniform welding current for consistent weld strength. Special interest may center around a brief discussion on methods of estimating instantaneous line voltage drops. This is just one of the problems in connection with resistance-welding regulation that is unique because of the application of phase-controlled ignition of the welding current.

43-93-ACO—Interim Report Emergency Measures to Increase Output of Generating Equipment and Systems; *AIEE Committee on power generation. 65 cents.* The AIEE standards committee, at its October 9, 1942 meeting, requested that each technical committee consider preparation of wartime guides to help the electrical industry find ways and means to "get more out of what it has." The power generation committee considered this assignment and decided that, because of many variables in construction and operation of generating stations and systems, they could best serve the industry by compiling a number of "hints" on this subject. The logical approach was to make a survey of what had been done by manufacturers and operating companies. Two subcommittees of the AIEE power generation committee have completed these assignments and this memorandum summarizes results of their work. One subcommittee, composed of manufacturers' representatives, assembled suggestions concerning generators. The other subcommittee, composed of operating-company representatives, obtained system data by means of a questionnaire which was quite widely distributed to the larger operating groups. Both of these subcommittee reports have been presented at the AIEE January technical conference in New York, the AIEE Kansas City technical meeting, and a joint meeting of the electrical equipment committee and prime movers committee of Edison Electric Institute. Many fine

comments and suggestions received from these conferences have been incorporated in this final report.

Electrical Machinery

43-76—Pole-Face Loss in Solid-Rotor Turbine Generators; *W. W. Kuyper (A '34). 30 cents.* This paper presents practical methods of predetermining the pole-face losses in solid-rotor turbine generators. The fundamental mathematical analysis is shown in detail together with the steps taken in simplifying the general equations for the range of problems usually encountered by the designer. Sample calculations, together with test results, are included. To make the paper complete within itself as a method of determining these losses, methods of calculating winding factors are included. From the information presented, it is expected that designers will be able to predetermine pole-face losses for substantially all cases encountered with greater facility and accuracy than has heretofore been possible.

43-82—Critical-Material Conservation in Induction-Motor Manufacture; *Henry M. Hobart (F '12). 15 cents.* The War Production Board's general conservation order *L*-221 is stated to contain a provision whereby the horsepower of a new electric motor shall not exceed the requirements of the specific job for which the motor is purchased. Compliance with this and other conservation provisions contained in the order is expected to conserve annually about 6,000 metric tons of copper and 55,000 metric tons of carbon steel. The present paper directs attention specifically to the case of general-purpose induction motors and describes means by which the desired conservation of critical metal can be effected promptly and without any impairment of the service reliability of the induction motors or any shortening of their life below the term of years experienced with the heretofore extremely conservative basis of rating of all general-purpose motors. The plan (which employs capacitors), ensures a high stalling load, and improved power factor and efficiency at all loads, involves no loss of time for preparing new designs, and conserves a greater amount of critical material than the amount envisaged in WPB *L*-221.

43-83—A New Type of Adjustable-Speed Drive for A-C Systems—II. *A. G. Conrad (M '40), S. T. Smith (A '43), P. F. Ordung (A '43). 15 cents.* The preceding paper of this series presented the theory and principles of operation of a new type of a-c motor and its control circuit. This system of speed control has the advantage of being economical from the standpoints of initial cost, efficiency of operation, and ability to correct power factor. However, these advantages are not realized unless the machine is suitably designed and its control circuit properly adjusted to supply the necessary voltages and currents. The purpose of this paper is to explain the design proportions and the adjustments of the supply voltages to provide for optimum operating characteristics.

43-87—Interim Report on Overloading Distribution Transformers; *AIEE transformer subcommittee. 15 cents.* The "Interim Report on Guides for Overloading Transformers and Voltage Regulators," which was presented at the AIEE summer convention, June 22, 1942, and published in AIEE *Transactions*, volume 61, 1942, September section, pages 692–4, gave information on the overloading of all types of transformers and voltage regulators. It was recognized, however, that the information given in that report might be somewhat conservative for distribution transformers. For this reason an additional report is being issued for use in conjunction with the above-mentioned report but specifically applicable to the operation of distribution transformers.

43-88—High-Voltage Power-Transformer Design; *M. B. Mallett (M '37). 20 cents.* A core-type power-transformer design with shielded high-voltage winding and graded insulation has been developed for application in the higher-voltage classifications, and up to the present time more than 250,000-kva capacity of this kind of transformer has been manufactured and placed in service. The design employs a new form of construction for high-voltage power transformers which has been called "distributed concentric construction." Outstanding characteristics of the distributed concentric-type transformer include

1. Reduced inherent reactance resulting in a reduction of critical materials for a given specification.
2. Ready adaptability to forced oil flow directed through the winding ducts, resulting in a reduction of critical materials for a given thermal capacity.
3. Simple and stable mechanical construction of windings, insulation, and shield.
4. Strategic distribution of voltage stress throughout the dielectric structure.

43-89—Quadrature Synchronous Reactance of Salient-Pole Synchronous Machines; *R. V. Shepherd (A '36), C. E. Kilbourne (M '37). 20 cents.* Quadrature synchronous reactance is of prime importance in determining the synchronizing coefficient P_n, which must be known accurately when synchronous machines are combined with mechanical drives having pulsating shaft torques, such as are found in Diesel or gas engines and reciprocating compressors. This paper presents refinements in the theory and calculation of x_q by taking into account the presence of slots in the stator and rotor surfaces. It presents a discussion of four methods of testing for x_q, two of which have not previously been published, and compares results obtained by calculation and by the four test methods. Results show that x_q can be calculated accurately over the wide range of machine parameters encountered in modern design and that a new method of test, the maximum lagging-current method described in the paper, yields dependable and accurate values of x_q and has great advantages in simplicity of technique and ease of accomplishment over all other methods presented.

43-99—The Calculation of Unbalanced Magnetic Pull in Synchronous and Induction Motors; *R. C. Robinson (A '39). 20 cents.* There is outlined in this paper a method of calculation of unbalanced pull which takes into account the combined effects of saturation, parallels, and primary reactance. The increased accuracy which this method affords should make possible more accurate predictions of mechanical deflections and critical speeds.

43-100—Distribution Factors and Pitch Factors of the Harmonics of a Fractional-Slot Winding; *M. M. Liwschitz (M '39). 15 cents.* The investigation of the fractional-slot windings with respect to their harmonic (differential) leakage, to noise, and so forth, is handicapped by the lack of a simple formula for the distribution factor of their harmonics. The object of this paper is to derive for the distribution factor of the fractional-slot windings formulas similar to those of the integral-slot windings. For this purpose the usual way of studying the fractional-slot windings, that is, the use of charts, is abandoned. The vector diagram of the different slots is used instead.

43-114—Operation of Nonsalient Pole-Type Generators Supplying a Rectifier Load; *M. D. Ross (M '42), J. W. Batchelor (A '38). 15 cents.* This paper presents test results of temperature measurements on a nonsalient pole-type generator, when supplying a rectifier load, and presents a method of calculating losses caused by rectifier harmonic currents. Calculations substantiated by tests indicate that for most applications one may neglect the effect of the rectifier harmonic currents on the temperature rise of the generator.

Electrochemistry and Electrometallurgy

43-95 ACO—Arc-Furnace Control by Regulex Exciters; *T. B. Montgomery (M '41), T. H. Bloodworth (A '41). 15 cents.* Separately excited commercial d-c generators are inherently power amplifiers with amplification ratios of 20 to 50. When two such machines are connected in tandem, the total ratio is the product of the ratios of the individual machines. Special design permits further resultant amplification and fits the machines for their use as regulators. Such amplifiers when used to regulate an electrical quantity require stabilization to prevent oscillation. This type of system applied to arc-furnace control has been made inherently stable. The control system is set at equilibrium at a given value of arc watts. Unbalance due to variations is transmitted through the closed system of the amplifier, without contacts, quickly establishing a *proportional* corrective speed in the electrode motor. Oscillograms show that arc energy is held to an average value, which has increased the heating rate per

unit of power expended under inherently rapidly fluctuating conditions.

43-96—Rotating Regulator for Arc Furnaces; *R. A. Geiselman, C. C. Levy (A'33), W. R. Harris (A'38). 15 cents.* Increased production of steel alloy for the war effort has brought about a wider use of electric-arc furnaces, and with this improvements have been made in automatic regulation of electrode position. The regulator described in this paper is of the rotating type which controls electrode position as determined by response to current in the electrode and voltage between the electrode and the furnace shell. Features and performance of a typical installation are illustrated.

Electronics

43-90—Theory of Rectifier—D-C Motor Drive; *E. H. Vedder (M'35), K. P. Puchlowski (A'43). 30 cents.* This paper is an introduction to the theory involved when a d-c shunt-wound motor is being operated from a rectifier. The theory applying to a system composed of a single-phase full-wave rectifier and d-c motor is developed mathematically. The equations derived are plotted graphically, showing current wave shapes, torque, and speed characteristics as influenced by motor armature resistance and inductance and by a-c supply voltage.

43-113—The Testing of Mercury-Arc Rectifiers; *H. L. Kellogg (A'41), C. C. Herskind (M'40). 30 cents.* This paper describes the testing procedure used in the development and manufacture of mercury-arc rectifiers. The high standard of performance required of rectifier equipment can be attained only by careful and comprehensive testing to assure elimination of possible causes of trouble. The arc-back phenomena encountered in rectifiers necessitate special testing methods which are discussed at length. Data are also included showing the results of tests. It is hoped that the material presented may be useful in the development of rectifier standards.

Industrial Power Applications

43-115—Load Pickup by a Group of Ignitron Rectifiers; *L. W. Morton (A'38), D. I. Bohn (M'41). 15 cents.* This paper analyzes the problem of energizing a large electrochemical-cell-line load from a group of d-c conversion equipments such as mercury-arc rectifiers. A description of widely used methods is included. Field tests covering a new grid-control scheme for starting a group of ignitrons are reported. Advantages of the new scheme are set forth. Oscillographic illustrations showing the results of these tests are particularly interesting. These field tests were comprehensive and of practical value, because they are full scale, having been made in a large aluminum plant on a cell line in regular normal operation. During these tests it was possible also to investigate other interesting phenomena in connection with switching large electrochemical loads on and off. Oscillographic illustrations of transient behavior caused by these switching operations are shown and will be of interest to many engineers who had been unable to do more than speculate on the problems in the past.

43-116—Thyratron Motor Control; *E. E. Moyer, H. L. Palmer (A'42). 20 cents.* One of the earliest applications of electronic devices was to control d-c motors. Recent developments greatly expand the number of industrial uses. Electronic motor control supplies the armature with variable-voltage direct current from a grid-controlled thyratron rectifier and supplies the field from Phanotron tubes for constant field excitation or thyratrons for field weakening control. Vacuum tubes actuate the thyratrons' saturable-reactor phase-shift circuits in response to signals of compensated armature voltage, armature current, and field voltage. These signals are compared against a glow-tube voltage standard, amplified, and applied in correct sequence to give desired motor characteristics. Switching duty on armature-circuit reversing contactors is minimized by the current-interrupting and -initiating action of the thyratron tubes. Similar controls are applicable to motor-generator-set drives to control the fields of these machines in correct sequence to maintain preset speed, armature voltage, and loop current conditions.

Instruments and Measurements

43-81—A Capacitance Bridge for Determining the Ratio and Phase Angle of Potential Transformers; *H. W. Bousman (M'36), R. L. TenBroeck (A'29). 15 cents.* A capacitance bridge for the calibration of instrument potential transformers up to 300 kv is presented in this paper. This bridge provides measurements which are correct within 0.1 per cent on ratio and three minutes on phase angle. There are within the bridge arrangements for testing its accuracy as determined by the stability of its component arms. It is particularly desirable to have this means of self-testing if transformers are to be tested in a laboratory which does not have extensive standardizing facilities. Further advantages beyond accuracy for standardization purposes are flexibility and ease of operation for production testing and low cost and small volume as compared to a high-voltage resistance potentiometer.

Power Transmission and Distribution

43-77—The Effect of Corona on Coupling Factors Between Ground Wires and Phase Conductors; *G. D. McCann (A'38). 20 cents.* Measurements of coupling factors between ground wires and phase conductors as a function of ground-wire voltage have been made for a sufficient number of cases to determine them for any of the standard transmission-line configurations. It was found that the effect of corona causes the coupling factor to increase appreciably with ground-wire potential. This effect is greater for positive-polarity than for negative-polarity potential of the ground wire. A study was made to show the visual dimensions of the ground-wire corona sheath, as compared to the effective increase in the ground-wire radius from the standpoint of its effect upon the coupling factors. Tests were also made to determine the conditions of flashover between a ground wire and floating phase conductor. Data were obtained showing the comparison between the breakdown values of standard test gaps and transmission-line insulation under these conditions.

43-80—Application of Carrier to Power Lines; *F. M. Rives (M'41). 30 cents.* This paper deals with the general problem of forming carrier circuits on transmission lines, describing the characteristics and functions of the principal tools used and the practices that have been followed in applying them. A method of computing the principal attenuation components and total attenuation of typical carrier circuits is presented in sufficient detail to be useful to the power utility engineer having little or no experience with carrier apparatus.

43-85—Safe Ratings for Overhead Line Conductors; *Leonard M. Olmsted (M'39). 30 cents.* Many factors must be considered in establishing safe ratings for overhead copper line conductors. Most important is the low-temperature annealing and loss of strength of the hard-drawn copper itself. Others are the effect of atmospheric conditions and line location relative to structures and topographical features tending to obstruct the wind. The actual construction details of the line, such as ground clearances, conductor splices, and connectors, and the policies of the personnel responsible for maintaining the line are pertinent. This paper attempts to show how these factors can be evaluated to establish operating ratings, indicates how readily available data can be utilized, and points out the lack of completely satisfactory data on other points. Procedure is stressed rather than results, as the influence of local conditions upon many of the factors precludes publication of ratings which are entirely safe to apply without careful investigation of the effect upon the copper conductors.

43-92—Distance Relay Protection for Subtransmission Lines Made Economical; *L. J. Audlin (M'35), A. R. van C. Warrington (A'31). 15 cents.* Less important transmission lines are usually protected with directional overcurrent relays. Much better protection and consequently improved service would be provided by modern high-speed distance relays but at several times the cost. What is required is a distance-relay arrangement considerably less expensive than the relays now used on high-voltage transmission lines but with as

nearly as possible the same characteristics. Such an arrangement is now available. The paper describes successful tests in the laboratory and on an actual system in this country with both natural and staged faults. The equipment consists of a single high-speed reactance relay which is enabled to protect all three phases by being automatically switched to the correct potential and current by a phase-selector relay. Compared with directional overcurrent relays for phase faults, the new scheme is easier to apply and gives complete selectivity, combined with high-speed tripping, at only a moderate increase in cost. Compared with conventional distance relays, the new scheme effects a saving in critical materials and labor, since one distance relay and an auxiliary relay replace three distance relays. This in turn reduces investment, panel space, and maintenance.

43-97—A Study of Voltage Transients in Arc-Furnace Circuits; *J. B. Fodtum (M '26), J. B. Rice (A '38). 25 cents.* In the history of the operation of arc furnaces there have been evidences of high-voltage surges. These have occasionally resulted in failure of associated electrical equipment. In the last three years an increasing amount of attention has been focused on this problem, chiefly because of the increasing number of arc-furnace installations and the seriousness of interruption to production. Following a general discussion of arc-furnace operating procedure and possible causes of voltage surges in furnace circuits, the paper presents the results of voltage surge measurements made on two typical arc furnace installations. The results of magnetic and cathode-ray oscillograms and of Klydonograph surge measurements are presented. Emphasis in the tests was placed on determining the source of voltage surges.

43-98—Practical Calculation of Electrical Transients on Power Systems; *R. D. Evans (F '40), R. L. Witzke (A '37). 25 cents.* This paper is devoted to the practical calculation of power-system transients and presents concepts, methods, and approximations selected with that objective in view. A method of calculation adapted to engineering work, designated as a "method of zeros and slopes," is described and illustrated by selected examples. Consideration is given to the physical interpretation of transients, particularly with the aid of the properties of equivalent circuits. The presentation is from the standpoint of the electrical engineer, who is accustomed to making steady-state calculations, but who has not given special study to the transient problem required by the mathematical approach generally used.

43-104—Guide for Wartime Conductor Temperatures for Power Cables in Service; *Association of Edison Illuminating Companies subcommittee on wartime temperatures for cable circuits. 20 cents.* This guide was prepared to aid in obtaining maximum practical utilization of underground power-cable circuits during wartime and still have tolerable rates of failure. Tables are given for recommended maximum conductor temperatures for normal daily operation and for occasional emergency operation for cables with the following insulations: impregnated paper of solid and oil-filled types, varnished cambric, and rubber. Factors affecting allowable loading and temperatures are discussed to indicate variations from the temperatures in the tables that should be made for given conditions and to indicate methods of obtaining maximum utilization with the temperatures set. All of the temperatures are substantially above previous standard temperatures and are recommended for use only in wartime to save critical materials, because their use is otherwise uneconomical and somewhat damaging to service reliability.

Power Transmission

43-105—Interim Report on Emergency Overloads on Overhead Conductors; *working group on towers, poles, and conductors of AIEE transmission subcommittee. 15 cents.* Present conditions in many cases make it necessary to establish new load limits for overhead conductors. This paper calls attention to the principal factors involved and the wide variation in available information on this subject, particularly in respect to annealing characteristics of conductors materials. Some factors affecting annealing are unknown and need to be investigated. Weather records should be used with caution and applied with full knowledge of conditions along the entire line. The effect on joints and possible heating of clamps or other magnetic fittings encircling the conductor are touched on. The report cautions against the use of overoptimistic values, resulting in serious damage to the conductors.

43-112—Frequency Modulation for Power-Line Carrier Current; *E. W. Kenefake. 15 cents.* The developments of frequency modulation in the low-frequency range below 200 kilocycles have indicated certain advantages for its use in power-line carrier. This paper discusses developments in the use of frequency modulation with a one-to-one deviation ratio for carrier-current applications. The basic characteristics of noise reduction by means of frequency modulation are discussed, and the results of various measurements with different types of interference are presented. These results point out that any interference arising from undesired amplitude modulation of the carrier is greatly reduced when frequency modulation is used. Since that type of interference is sometimes encountered on power lines, frequency modulation can be used to advantage in those cases. By the use of a one-to-one deviation ratio it is shown that the band width of a frequency-modulated channel can be made the same as in an audio-frequency modulated channel. This overcomes many difficult application problems.

Protective Devices

43-79—Pilot-Wire Relaying on a Metropolitan System; *T. G. LeClair (F '40), E. L. Michelson (A '37). 20 cents.* The inherent selectivity of pilot-wire relaying makes it an ideal method for protecting transmission lines. This paper describes the pilot-wire systems employed on a large metropolitan power system where this type of relaying is used extensively. Three different arrangements are used, all of which are described in the paper. All schemes are similar in principle and use circulating a-c currents to make a direct comparison between the currents at the two ends of the main transmission line. This paper shows the net effect of pilot-wire troubles on relay operation. It points out that induced voltages on pilot wires are not a serious problem on an underground system. It also gives an analysis of relay operations for a ten-year period which indicates a relatively good record for pilot-wire relaying. It shows that pilot-wire relaying is more reliable than other types of high-speed relays. The paper discusses the relative merits of owned pilot wires versus leased telephone wires. Owned wires have a higher cost but offer several operating advantages. It compares pilot-wire relaying with carrier-current relaying. Pilot-wire relaying can be applied economically only on relatively short transmission lines, but, where applicable, it provides a more reliable form of protection than carrier-current relaying.

43-91—Carrier-Current Differential Protection for Transformer Banks; *T. A. Cramer (A '41). 15 cents.* Under present conditions where new manufacturing plants must be served with as little additional equipment as possible, the power-system designing engineer frequently finds it expedient to install a transformer with only a low-voltage circuit-breaker. This arrangement presents a problem for the protection engineer since the reactance of the transformer bank makes it difficult for the remote relays to recognize faults in the low-tension winding. This paper describes a method of completing the protection of the transformer bank by adding an audio-frequency modulating signal to the standard carrier-current pilot-relaying channel to trip the remote circuit breaker when the transformer differential relay operates.

43-102—The Cause and Control of Some Types of Switching Surges; *T. W. Schroeder (A '37). 15 cents.* Switching-surge overvoltages, particularly those resulting from interrupter restriking when opening the normal balanced charging currents of cable circuits, long high-voltage lines, or large capacitor banks, recently have received attention in the technical literature. This paper presents the results of analyses of other methods of reducing the possibility and magnitude of these overvoltages, namely, the dependence on saturable transformer windings in parallel with the capacitance to discharge it following the first interruption. The effect of trans-

former size relative to the capacitance and the method of transformer connection are discussed. "Low-side" switching of lines and cables is indicated to be very effective. A summary of the capacitive-circuit switching problem and its solution by the use of resistor-shunted interrupters is given. In addition, an analysis is made of the problem of off-current-zero interruption of transformer magnetizing current. This analysis indicates the amount of capacitance required in shunt with the transformer (and switched with it) to hold the voltage resulting from an interruption at the crest of the current wave to any allowable value.

43-103—A New High-Interrupting-Capacity Fuse for Voltages Through 138 Kv; *H. H. Fahnoe (A '35). 15 cents.* The reliable performance of high-interrupting-capacity fuses in the intermediate-voltage field has increased interest in the application of such fuses for higher voltages. A new fuse has been developed to meet the requirements for service on important transmission circuits operating at 44 to 138 kv. The requirements for this service are discussed along with other factors that prevent such a fuse from being a mere enlargement of lower-voltage fuses. A description is given of the new boric-acid fuse which, for its interrupting capacity, is light in weight, permitting the dropout design necessary at these higher voltages. The data and oscillograms presented cover high-power laboratory tests under all possible fault conditions and assure reliable short-circuit protection on systems capable of delivering three-phase symmetrical short circuits of 1,000,000 kva.

43-110—A Simple Method for the Determination of Bushing-Current-Transformer Characteristics; *Stuart D. Moreton (A '41). 20 cents.* In line with the present trend toward the calculation of bushing-current-transformer characteristics from typical excitation curve data, this paper presents an analysis of the errors introduced by the simple method of "inphase" addition of exciting current and secondary current. These errors are compared with the expected variation in ratio correction factor due to variation of the parameters, especially the iron core. The conclusion is reached that this simple method gives results that are not only well within this expected variation but also well within engineering accuracy. An extension of this method is presented for the determination of phase-angle errors with a little extra effort. Inphase addition is expanded by a graphical process, so that only one point need be calculated to draw a complete characteristic curve. This is performed by means of one template that is good for all burdens, ratios, and voltage ratings. A special co-ordinate paper is presented that gives the ratio correction factor in terms of either the per cent rated primary current or the per cent rated secondary current. It has the advantage of giving the secondary current directly in terms of the primary current.

43-111—Report on Application of Lightning Protective Devices in Wartime; *AIEE lightning arrester subcommittee. 15 cents.* This report by the lightning arrester subcommittee has been prepared to suggest ways and means of applying protective devices such as lightning arresters in such a manner as to save critical materials either directly or indirectly. Eight suggestions for accomplishing this are presented and discussed. These are:

1. Applying arresters on basis of voltage rating.
2. Rebuilding and revamping old arresters.
3. Short connections between arresters and equipment.
4. Line-type arresters in place of station-type.
5. Protection of equipment not already protected.
6. Protective devices other than arresters.
7. Shielding of stations
8. Tests and maintenance of arresters.

A careful study of the problem of supplying overvoltage protection, particularly by the use of lightning arresters, should yield considerable over-all benefits, not only in saving of critical materials at the present time, but also in reducing damage to expensive and hard-to-replace equipment, as well as improving continuity of service to power systems.

43-117—A New High-Speed Balanced-Current Relay; *V. N. Stewart (A '38). 15 cents.* A high-speed induction-cylinder-type relay has been developed in which the operating-coil circuit has an inherent delay of about a cycle, because of the time required to build up current in a resonant circuit. The restraining coils of the relays are lagged with copper rings and produce restraint in a small fraction of a cycle. Complete description of operating principles and tests are covered by this paper.

43-118—Relay Protection for Three Terminal Lines; *M. A. Bostwick (A '42), E. L. Harder (M '41). 15 cents.* The war, with its attendant shortage of critical materials, has led to a considerable increase in the number of tapped lines. This paper deals with the method of protecting circuits of this kind under three headings:

1. Pilot-wire protection, a-c and d-c schemes.
2. Carrier-current protection.
3. Other protective schemes.
   Directional overcurrent or network.
   Distance type.

Three terminal lines are classified into three types with regard to other system connections between the terminals connected by the line in question. These are classified further as to power sources to aid in analyzing limiting conditions for relay applications. Typical operating characteristics of a-c pilot-wire equipment for three terminal lines are shown. In general, in dealing with pilot-wire carrier, and other types of protection, those problems peculiar to application on three terminal lines are analyzed, and methods are given for solving some of the more troublesome problems.

43-119—Interim Report on Application and Operation of Out-of-Step Protection; *AIEE working group of relay subcommittee. 20 cents.* Out-of-step protection of synchronous machines and system interconnections is now demanding serious consideration because

1. The heavy loading of machines and transmission lines have introduced many stability problems.
2. Outages due to out-of-step conditions may interfere seriously with the war effort.

The relay subcommittee has, therefore, considered it timely to prepare a report on the subject and has appointed a working group for that purpose. The report describes briefly the phenomena of out of step, the methods of protection available, and a cross section of the practices and requirements of representative utility systems.

Safety

43-94 ACO—Practical Accident Prevention in Small Groups; *O. S. Hockaday (M '28). 15 cents.* The stress of war production places on industrial management a keener responsibility for preventing accidents. Large corporations usually have safety departments to direct this effort, but scattered over the country are thousands of industrial concerns of modest proportions which are not in position to set up formal safety organizations. Suggestions are offered in this paper as to how the superintendent of a small group may develop within his existing personnel an effective safety program.

Transportation

43-78—Adequate Electrical Maintenance Essential to Transportation; *W. J. Clardy (M '39). 15 cents.* The demand for public transportation is increasing rapidly under present conditions of accelerated industrial activity. Adequate maintenance of electrical apparatus on rolling stock is essential to avoid impairment to the war effort. Measures which will help to retain generators, motors, and control in service practically 100 per cent of the time are proper operation, effective inspection, preventive maintenance, keeping apparatus clean, accurate adjustments, prompt worn part replacements, undelayed commutator conditioning, use of improved insulation, and correct lubrication. More careful attention to all of these factors during the present emergency will assure maximum rolling-stock availability.

PERSONAL ....

C. H. Sanderson (A '07, F '18) system planning engineer, Consolidated Edison Company of New York (N. Y.), Inc., has retired. Mr. Sanderson who was born in 1880 commenced his engineering career in 1901 with a year of shopwork at the Westinghouse Electric and Manufacturing Com-

pany, East Pittsburgh, Pa., after which he was transferred to the drafting department. In 1906 he did switchboard and power-station design and in 1919 was given supervision of this work for the eastern United States and all foreign trade. As general engineer from 1911 to 1913 he assumed the duties of commercial engineer salesman. He worked as electrical engineer for the Havana (Cuba) Electric Railway, Light, and Power Company from 1913 to 1917. From 1918 to 1920 he was connected with Frank G. Robbins Company, Havana. His association with the New York Edison Company dates from 1921 when he took the position of assistant electrical engineer and assistant system engineer. In 1937 he was made system planning engineer. He has written and edited books and is editor in chief of "American Standard Definitions of Electrical Terms." He is also a member of the Edison Electric Institute, the Professional Electrical Engineers, the American Standards Association, and the United States Chamber of Commerce.

J. H. Gardner (A '25, M '34) formerly lieutenant colonel, Signal Corps, United States Army, and director of the Aircraft Laboratory, Wright Field, Dayton, Ohio, was among the 52 temporary brigadier generals recently appointed by President Roosevelt. He holds the degrees of bachelor of science (1913) and master of science (1915) from Union College and the degree of master of science in electrical engineering (1924) from Yale University. Before joining the army he was employed by the General Electric Company, Schenectady, N. Y., and Chicago, Ill., from 1913 to 1917. He served as radio and telephone officer in the Field Artillery from 1917 to 1919. From 1919 to 1921 he was with the Intelligence Section of the army of occupation in Germany. In 1921 he was transferred to the Signal Corps and in succession became assistant to the signal officer, Fifth Corps Area, Columbus, Ohio, in 1925, executive officer for research and engineering in the office of the chief signal officer, Washington, D. C., in 1926, executive officer of the Signal Corps Laboratories, Fort Monmouth, N. J., in 1931, and executive officer of the Aircraft Laboratory, Dayton in 1939. He was made director of the laboratory in 1940. In 1935 he was promoted from the rank of captain to major and in 1941 to lieutenant colonel.

H. Y. Hall (A '03, F '27) production superintendent, Consolidated Edison Company of New York (N. Y.), Inc., recently retired. Mr. Hall received the degree of bachelor of science in electrical and mechanical engineering from the Alabama Polytechnic Institute in 1900. He immediately entered the testing department of the General Electric Company, Schenectady, N. Y. In 1905 he received the degree of electrical engineer. He was employed in the operation and testing department of the Manhattan Railway Company, New York, N. Y., from 1902 to 1906. After a year as construction foreman for J. G. White Company, New York, N. Y., he joined the Southern Pacific Railroad Company, San Francisco, Calif., in 1907 and remained with that company until he established his own consulting engineering practice in San Francisco in 1914. From 1917 to 1919 he worked as design engineer for the Neuelectric Transmission Company, Cleveland, Ohio, and for J. Livingston Company, Cleveland, from 1919 to 1921. He entered the employ of the United Electric Light and Power Company in 1921 as superintendent of their Hell Gate Station. In 1937 he became superintendent of their Waterside Station and in 1942 production superintendent.

W. H. Matthies (M '26, F '29) switching development director, Bell Telephone Laboratories, New York, N. Y., has retired. Born in Hamburg, Germany, in 1879, he graduated from the Massachusetts Institute of Technology in 1902. In the latter year he joined the Western Electric Company, New York, N. Y., as student engineer and for two years following held the position of equipment engineer. He was made chief engineer of the company's Berlin, Germany, branch in 1905. In 1911 he was transferred to Antwerp, Belgium, to the staff of the European chief engineer. There he supervised the work of the London, Antwerp, Paris, and Berlin branches. From 1912 to 1916 he specialized in machine switching development and in 1916 took charge of the machine switching laboratory in New York. In 1935 he was named switching development director of Bell Laboratories. He holds numerous patents and has been active in the development of the panel and crossbar systems and dial operation.

H. B. Leach (A '18) assistant superintendent, Consolidated Edison Company of New York (N. Y.) Inc., has retired. Mr. Leach, who was born at Wilmington, Del., August 12, 1886, had completed 31 years with the Edison company and its predecessors. He entered the employ of the New York Edison Company in 1913 after five years (1905–10) with the Wilmington (Del.) City Electric Company and three years (1910–13) with the Westchester Lighting Company, Mount Vernon, N. Y. Until 1918 when he was transferred to the test department he worked in the meter department of the Edison company. In 1920 he was made chief tester and in 1923 became foreman of the test division of the United Electric Light and Power Company. He was named general foreman of the meter and test department in 1930. Appointed assistant superintendent of the New York Edison Company in 1935 he continued in that position with the Consolidated Edison Company after the 1936 merger of the New York companies.

R. S. Elberty (A '25, M '35) formerly electrical engineer with the Landis Tool Company, Waynesboro, Pa., has opened his own consulting engineering office at Fort Lauderdale, Fla. Mr. Elberty received the degree of electrical engineer in 1925, and the degree of bachelor of science in commerce in 1929 from the University of Cincinnati. From 1925 to 1929 he worked as electrical engineer for the American Laundry Company, Cincinnati, Ohio. After a year as chief engineer with B. A. Wesche Electric Company, Cincinnati, he became associated as general engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., from 1929 to 1937. In the latter year he joined the Landis company.

J. E. Hayes (A '03) formerly president of the New Jersey Zinc Company, New York, N. Y., has been elected chairman of the board of that company. He has been president of the company since 1927. In addition he holds the position of president of the New Jersey Zinc Sales Company, the Empire Zinc Company, the New Jersey Zinc Company of Pennsylvania, Palmerton, the Palmerton (Pa.) Lighting Company, Palmerton Water Company, the Palmerton Telephone Company, the Chestnut Ridge Railroad Company, and the Saucon Valley Iron and Railroad Company. He received the degree of civil engineer in 1895 and the degree of electrical engineer in 1897 from Princeton University.

G. W. Pierce (A '11) professor of physics and communication engineering, Harvard University, Cambridge, Mass., recently was awarded a Franklin Medal and a certificate of honorary membership to the Franklin Institute. Doctor Pierce was honored for his development of "electrically squeezed" quartz crystals used to narrow the range of radio frequencies. He has been teaching at Harvard University since 1907 when he joined the faculty as assistant professor of physics. In 1920 he was the recipient of the medal of the Institute of Radio Engineers for distinguished service, to radio engineering.

G. B. Kersey (A '14, M '26) supervising field engineer, Commonwealth Edison Company, Chicago, Ill., has retired. Born May 24, 1883, in Lebanon, Ind., he was graduated from Purdue University with the degree of bachelor of science in electrical engineering in 1905. In the latter year, as a substation operator, he commenced a 38-year association with the Edison company. He was transferred to the engineering department as draftsman in 1907. Subsequently he became head draftsman and designing engineer. In 1922 he was made field engineer and in 1932 supervising field engineer.

W. E. Poor (A '15) executive vice-president Hygrade Sylvania Corporation has been elected president of Sylvania Products, Inc. Mr. Poor was assistant manager of the Hygrade Lamp Company, Salem, Mass., from 1909 to 1922, when he became chief engineer. In 1930 when his company combined with Sylvania Products Com-

pany he was appointed vice-president in charge of manufacturing. He was made executive vice-president of Hygrade Sylvania Corporation in 1940.

C. A. Butcher (M '22) formerly assistant manager of the district manufacture and repair department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been made manager of that department for the Pacific Coast district of the Westinghouse company, Emeryville, Calif. Mr. Butcher has been assistant to the national manager since 1941. From 1929 to 1936 he was eastern engineering manager and eastern service manager from 1936 to 1941.

J. E. O'Brien (A '29 M '39) has been appointed a major, United States Marine Corps. Major O'Brien was formerly head of the Special Problems Section, Technical Standards Division, Rural Electrification Administration. Prior to his connection with the Rural Electrification Administration, he was a member of the electrical engineering staff of the Catholic University, Washington, D. C.

D. C. Jackson, Jr. (A '23, F '30) on leave of absence from his position as dean of the school of engineering, University of Notre Dame (Ind.) has been promoted from the rank of major in the United States Army to that of lieutenant colonel, Frankford Arsenal, Philadelphia, Pa. Lieutenant Colonel Jackson served as an officer in the Coast Artillery from 1917 to 1919.

E. J. Van Deusen (A '35,) M '43 assistant electrical engineer for the Mason and Hanger Company in charge of outside electrical distribution construction, Badger Ordnance Works, Baraboo, Wis., has been commissioned as lieutenant in the United States Naval Reserve. He has been on leave of absence from the Wisconsin Power and Light Company, Madison, for the past year.

H. S. Osborne (A '10, F '21) formerly assistant chief engineer, operations and engineering department, American Telephone and Telegraph Company, New York, N. Y., has been appointed chief engineer of that department. Mr. Osborne is currently serving as AIEE president. For a fuller biography see *Electrical Engineering*, January 1943, page 35.

G. W. Bower (A '18, M '40) formerly assistant to the Camden district superintendent has been appointed engineer in the general office, Public Service Electric and Gas Company, Newark, N. J. Mr. Bower has been with the Public Service company since he graduated from Drexel Institute of Technology in 1914.

J. K. Johnson (A '28) formerly engineer in charge of Chicago (Ill.) laboratory, Hazeltine Electronics Corporation, has become a special representative in the Office of Procurement and Material of the Office of the Under Secretary of the Navy, Washington, D. C. He had been with the Hazeltine corporation since 1934.

J. M. Standring (A '40) formerly senior staff engineer with the Bell Telephone Company of Pennsylvania, Philadelphia, has been transferred to the transmission group in the operations and engineering department of the American Telephone and Telegraph Company, New York, N. Y.

K. A. Ganssle (A '40) formerly engineer, general engineering department, Southern California Telephone Company, Los Angeles, has been transferred to the equipment and building section of the plant engineering division, American Telephone and Telegraph Company, New York, N. Y.

W. G. Steinbright (A '40) formerly assistant to the general superintendent of the suburban transmission and distribution division of the Philadelphia (Pa.) Electric Company has been appointed superintendent of the Schuylkill division of that company.

J. F. Atkinson (A '41) is now a lieutenant in the Signal Corps, United States Army, Galveston, Tex. Mr. Atkinson is on leave from the Technical Standards Division, Rural Electrification Administration, where he is an associate engineer.

C. H. Weaver (A '37) formerly commercial engineer in the marine sales department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed manager of the marine section. He has been with the Westinghouse company since 1936.

J. E. H. Stevenot (A '13, M '17) formerly vice-president and general manager of the Philippine Long Distance Telephone Company, Manila, is now a colonel in the United States Signal Corps and deputy chief of staff of General Douglas MacArthur.

J. B. Rees (M '31, F '32) equipment and building engineer, operations and engineering department, American Telephone and Telegraph Company, New York, N. Y., has been appointed to the Telegraph Operations Industry Advisory Committee of the War Production Board.

C. R. Camp (A '20, M '25) formerly field engineer, Commonwealth Edison Company Chicago, Ill., has been appointed supervising field engineer. He has been with the Edison company since 1915 as generating station operator, head draftsman, and, since 1927, as field engineer.

D. E. Basler (A '39) has been promoted to Captain, Signal Corps, United States Army, Washington, D. C. Captain Basler is on leave from his position as associate engineer, Technical Standards Division, Rural Electrification Administration.

J. W. Carpenter (A '40) formerly associate engineer, Technical Standards Division, Rural Electrification Administration, has been called to active duty. He holds a commission as a lieutenant, junior grade, in the United States Naval Reserve.

D. G. Housley (A '41) is now serving as a lieutenant, Army Air Forces Boca Raton Field, Fla. He is on leave from the Technical Standards Division, Rural Electrification Administration, where he is an assistant engineer.

W. A. Lewis (A '42) an ensign in the United States Naval Reserve, has been called to active duty. He is an assistant engineer on leave from the Technical Standards Division, Rural Electrification Administration.

N. W. Matthews (A '39) is now a second lieutenant, United States Marine Corps, Camp Murphy, Fla. Formerly, he was an associate engineer, Technical Standards Division, Rural Electrification Administration.

B. O. Watkins (A '43) has been commissioned a lieutenant, junior grade, in the United States Naval Reserve. Lieutenant Watkins was head of the Operating Problems Unit, Technical Standards Division, Rural Electrification Administration.

W. L. Cisler (M '35) assistant chief engineer, electrical engineering department, Public Service Electric and Gas Company, Newark, N. J., is chief of equipment production in the power section of the Office of War Utilities.

Howard Dingle (A '07, M '41) president of the Cleveland Worm and Gear Company, has been named to newly formed Gear and Speed Reducer Industry Advisory Committee of the War Production Board.

N. B. Hinson (A '19, F '35) chief engineer, Southern California Edison Company, Ltd., has been elected chairman of the Electric Power Interchange Committee which was formed to meet California's demands for power in war production.

A. W. Robertson (A '27) chairman of the board, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., has been awarded the honorary degree of doctor of engineering by Stevens Institute of Technology.

F. W. Petit (A '23, M '37) formerly assistant engineer, Consolidated Edison Company of New York (N. Y.), Inc., is now employed by the Columbia University National Defense Laboratories, New York, N. Y.

J. T. Barron (A '07, F '27) vice-president in charge of electric operation, Public Service Electric and Gas Company, Newark, N. J., has been elected to a three-year

term on the board of directors of the American Standards Association.

L. C. Larson (A '23, M '29) professor of electrical engineering, University of Wisconsin, Madison, has been appointed chairman of the Madison Section of the AIEE to fill the unexpired term of E. J. Van Deusen (A '35).

J. R. Oberholtzer (A '39) Associate Engineer, Technical Standards Division, Rural Electrification Administration, has been commissioned a second lieutenant in the Signal Corps, United States Army.

K. J. Plucknett (A '39) associate engineer, Technical Standards Division, Rural Electrification Administration, has been commissioned an Ensign in the United States Naval Reserve, Brighton, Mass.

W. T. Smith (A '40) associate engineer, Technical Standards Division, Rural Electrification Administration, has been commissioned a lieutenant in the United States Marine Corps.

J. L. Thurston (A '41), associate engineer, Technical Standards Division, Rural Electrification Administration, is now a Lieutenant in the Signal Corps, United States Army, Camp Maxey, Tex.

J. E. Dingman (M '37) division plant superintendent, American Telephone and Telegraph Company, New York, N. Y., has been appointed employees' relation manager in the long lines department.

P. V. Plummer (A '33) engineer with the United Illuminating Company, New Haven, Conn., has been made superintendent of electrical construction and maintenance in the production department.

O. E. Anderson (A '29) formerly staff assistant to the superintendent of construction, Commonwealth Edison Company, Chicago, Ill., has been made assistant superintendent of construction.

N. K. Davis (A '40) chief engineer of the Georgia Public Service Commission, Atlanta, is chief of the allocations section of the power division of the Office of War Utilities.

J. E. Moore (A '12) consulting engineer, Ebasco Services, Inc., New York, N. Y., is chief of the power supply section of the power division of the Office of War Utilities.

Norman Knight (M '37) chief engineer of the western area of the Bell Telephone Company of Canada, Toronto, Ont., has been elected president of the Electric Club of Toronto.

W. E. Melarkey (A '27) formerly executive engineer of The Hilo (Hawaii) Electric Light Company, is now lieutenant commander in the 14th Naval District at Pearl Harbor, Hawaii.

Edward Falck (A '40) special assistant to the vice-president, Consolidated Edison Company of New York (N. Y.), Inc., is deputy director of the Office of War Utilities.

H. J. Billica (A '36, M '36) formerly with the Office of War Utilities, War Production Board, Washington, D. C., is now employed in the Washington office of the Copperweld Steel Corporation.

J. G. Harden (A '34) toll plant chief, Indiana Bell Telephone Company, Indianapolis, has been transferred to Bell Laboratories, Inc., New York, N. Y., for the duration of the war.

Wilfred Sykes (A '09, F '14) president of the Inland Steel Company, Chicago, Ill., has been awarded the honorary degree of doctor of engineering by the Illinois Institute of Technology.

C. C. Johnson (M '20) president of the American District Telegraph Company, New York, N. Y., has been nominated a vice-president of the National Fire Protection Association for 1943.

A. R. Small (M '37) president of the Underwriters' Laboratories, Inc., Chicago, Ill., has been elected to a three-year term on the board of directors of the American Standards Association.

W. L. Crosby (A '41) formerly foreman in the test bureau of the Consolidated Edison Company, New York, N. Y., has joined the Submarine Signal Company, New York, N. Y.

W. C. White (A '23, M '30) director of the electronics laboratory, General Electric Company, Schenectady, N. Y., has been named to the board of directors of the Institute of Radio Engineers.

J. J. Ryan (M '23) general superintendent, meter bureau, Consolidated Edison Company, New York, N. Y., has been elected president of the Edison Savings and Loan Association.

Vannevar Bush (A '15, F '24) president of the Carnegie Institution of Washington (D. C.), has been awarded the honorary degree of doctor of science by Stevens Institute of Technology.

E. O. Shreve (A '06) vice-president, General Electric Company, Schenectady, N. Y., was recently elected a member of the board of directors of the United States Chamber of Commerce.

D. J. O'Conor, Jr. (A '38) has been appointed assistant chief engineer of the Formica Insulation Company, Cincinnati, Ohio. He has been employed by the Formica company since 1940.

R. L. Morris (M '31) assistant engineer, Consolidated Edison Company of New York (N. Y.), Inc., has received a wartime leave of absence to join the Tel Autograph Corporation, New York, N. Y.

L. A. Nettleton (A '21, M '26) formerly assistant engineer, Consolidated Edison Company of New York (N. Y.), Inc., has joined the Massachusetts Institute of Technology, Cambridge, Mass.

H. S. Orcutt (A '26) formerly assistant engineer, Consolidated Edison Company of New York (N. Y.), Inc., is now with the Federal Radio and Telephone Company, East Newark, N. J.

Norman Franks (A '41) manager of the Toronto district, Canadian General Electric Company, Ltd., Toronto, has been elected president of the Electric Service League of Toronto.

H. W. King (A '37) formerly assistant engineer, Consolidated Edison Company of New York, Inc., is now with the Anaconda Wire and Cable Company, Hastings, N. Y.

C. E. Dean (A '23, M '37) radio engineer, Hazeltine Service Corporation, New York, N. Y., has been elected vice-president o, the Radio Club of America.

L. E. Packard (A '40, M '41) engineer, General Radio Company, New York, N. Y., has been elected recording secretary of the Radio Club of America.

OBITUARY • • • •

Philip Herd (M '21) partner in Wilson and Herd, Ltd., Johannesburg, Union of South Africa, died on August 19, 1942. Born November 12, 1870, at Birkenhead, Cheshire, England, he received his early electrical training as apprentice electrical engineer for the Telegraph Manufacturing Company, Ltd. (now British Insulated Cables, Ltd.), Helsby, Cheshire, England, from 1886 to 1889. From 1890 to 1896 he was employed successively by the White Star and the Dominion Steamship Lines, and the Liverpool (England) Electric Overhead Railway. In 1897 and 1898 he engaged in insulating and operating gold mine electrical plants in South Africa and at electrical construction in Beird, Portuguese East Africa. Joining the staff of the South African General Electric Company, Ltd., Johannesburg, in 1899, he entered the test course in the foreign engineering department of the General Electric Company, Schenectady, N. Y. In 1900 he returned to South Africa and remained in the service of the General Electric Company as engineer and manager for Cape Colony, Union of South Africa, until 1916. In the latter year he became a member of the engineering firm of F. Peabody Rice and Wilson. He had been managing director of this firm since 1916.

Robert Anderson Carter, Jr. (A '09) manager of gas production, Consolidated Edison Company of New York (N. Y.) Inc., died April 2, 1943. Born August 9, 1884, in Brooklyn, N. Y., he entered the employ of the Consolidated Gas Company, New York, N. Y., in 1902. After a year

and a half in various training positions, he was made assistant engineer in 1903, and a cadet engineer in 1904. He became assistant engineer with the Central Union Gas Company, New York, N. Y., in 1905. In 1908 he joined the Westchester Lighting Company, New Rochelle, N. Y., as cadet engineer. From 1922 to 1928 he was engineer of manufacture for the Consolidated Gas Company and the Astoria (N. Y.) Light, Heat and Power Company. He was named vice-president of the Astoria company in 1928. When that company merged into the Consolidated Edison company in 1936 he was appointed engineer and later manager of gas production for the Consolidated Edison company. He was the author of several technical papers and a member of the American Gas Association, the American Society of Mechanical Engineers, the Illuminating Engineering Society the Society of Gas Engineering, and the Society of Gas Lighting.

Francis Ogden Blackwell (A '00, M '03) president of Viele, Blackwell and Buck, New York, N. Y., died on April 11, 1943. Mr. Blackwell was born June 23, 1868, in New York and received the degree of civil engineer from Princeton University in 1887. During 1887 and 1890 he worked for the Bentley-Knight Electric Railway Company, New York, N. Y. In 1890 he joined the Thomson Houston Electric Company, Lynn, Mass., as assistant engineer of the railway division. When that company became part of the General Electric Company, Schenectady, N. Y., in 1892 he was made chief engineer in the power and mining department. As such he was responsible for that company's development of long-distance power transmission. In addition he built mining plants in California, Oregon, Utah, Minnesota, Louisiana, and Mexico. He resigned in 1906 to form his own consulting engineering firm in New York, N. Y. During World War I he served as consulting engineer to the United States Navy and War Departments. More recently he was engaged as consultant on the Muscle Shoals project and on the design of the St. Lawrence Waterway.

John Henry Schroder (M '42) Lieutenant commander, United States Navy, San Diego, Calif., died May 3, 1943. Born December 1, 1899, in Walhalla, S. C., he received the bachelor of science degree in mechanical engineering from Clemson College in 1921. From 1918 to 1920 he served in the United States Army. He commenced his engineering career in the construction division of the electrical engineering department of the Public Service Production Company, Newark, N. J., from 1921 to 1923 when he became an engineering assistant. From 1925 to 1927 he worked on design and purchase of materials for the Public Service Gas and Electric Company. In 1928 he joined the United Engineers and Constructors, Newark, N. J., where he designed switching tations until 1936. Returning to the Public Service Gas and Electric Company in 1936 he was assigned as sponsor engineer doing rebuilding and installation for switching and generating stations. In 1942 he received a leave of absence for the duration of the war to serve in the Navy.

Henry Clay Hart (M '27) vice-president of the Cuban Telephone Company, Havana, died on March 23, 1943. Mr. Hart, who was born January 22, 1881, in Jacksonville, Fla., entered engineering as a draftsman with the United States Government of Intervention in Cuba in 1901. During 1903 and 1904 he supervised a surveying party for the Bahia Honda (Cuba) Land and Improvement Company. He had charge of a surveying corps as well as being resident engineer with the Havana (Cuba) Central Railway in 1905 and 1906. He held the positions of engineer and general superintendent of the Electricity and Traction Company of Santiago, Cuba, in 1907, district engineer with the Department of Public Work, Santiago, in 1908, and engineer with T. H. Huston, General Contractor, Havana, in 1909. His association with the Cuban Telephone Company commenced in 1910, when he took charge of the company's long distance right of way. Subsequently he became cable engineer, plant engineer, Havana plant superintendent, general plant superintendent, assistant chief engineer, and chief engineer. He was named vice-president in 1927.

Henry D. Reed (A '94, M '13) president of the Bishop Wire and Cable Corporation, New York, N. Y., died April 27, 1943. Born in 1869 at Poughkeepsie, N. Y., he graduated from Stevens Institute of Technology in 1892. He immediately joined the Bishop Gutta Percha Company, which became the Bishop Wire and Cable Corporation in 1925, and was placed in charge of cable testing. From 1901 to 1908 he was general superintendent in charge of the manufacture of electric cables. He became vice-president of the company in 1909 and president in 1919. In addition he served as president of Bishop Industries, Inc., the Glenwood Holding Company, the No-Slip Rubber Company, and the Peter's Manufacturing Company.

Dana Ripley Bullen (A '02) retired assistant vice-president of the General Electric Company, Schenectady, N. Y., died May 10, 1943. Mr. Bullen was born at Wakefield, Mass., August 13, 1864, and received the bachelor of arts degree from Brown University in 1886. His entire career was spent with the General Electric Company and its predecessor the Thomson-Houston Electric Company, Lynn, Mass., where he entered the construction department in 1887. He was transferred to the commercial department in 1890 and remained there until 1915 when he became manager of the supply department. In 1923 he was appointed assistant vice-president. He retired in 1933. He had been a director of the Locke Insulator Corporation.

MEMBERSHIP ..

Recommended for Transfer

The board of examiners, at its meeting on May 20, 1943, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

DuBose, M., general manager, Saguenay Power Company, Montreal, Que., Canada.
Hazen, H. L., professor in charge, department of electrical engineering, Massachusetts Institute of Technology, Cambridge, Mass.
Housley, J. E., district power manager, Aluminum Company of America, Alcoa, Tenn.
Liversidge, H. P., president, Philadelphia Electric Company, Philadelphia, Pa.
Lyman, W. J., engineering assistant to manager, Duquesne Light Company, Pittsburgh, Pa.
Robertson, B. L., associate professor of electrical engineering, University of California, Berkeley, Calif.
Skeats, W. F., research engineer, General Electric Company, Philadelphia, Pa.
Stiner, H. W., electrical engineer, coal division, Koppers Company, Pittsburgh, Pa.

8 to grade of Fellow

To Grade of Member

Aicher, L. C., assistant electrical engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Arnold, E. J., division transmission and protection engineer, Michigan Bell Telephone Company, Saginaw, Mich.
Arthur, R. S., electrical sales engineer, General Electric Company, Schenectady, N. Y.
Baker, D. H., transmission and protection engineer, Michigan Bell Telephone Company, Detroit, Mich.
Bath, F. W., assistant to manager, electrical department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Dickinson, W. H., engineer, Standard Oil Development Company, Elizabeth, N. J.
Diehl, G. S., assistant to superintendent of operation, Pennsylvania Water and Power Company, Baltimore, Md.
Doan, G. H., assistant to superintendent of electric system, Detroit Edison Company, Detroit, Mich.
Donelson, L. E., toll transmission engineer, Michigan Bell Telephone Company, Detroit, Mich.
Elge, E. A., field engineering, power transmission department, General Electric Company, Pittsfield, Mass.
Estrada, H., superintendent of economy division, Philadelphia Electric Company, Philadelphia, Pa.
Gaty, L. R., assistant electrical engineer, Philadelphia Electric Company, Philadelphia, Pa.
Heine, G. M., electrical engineer, Cutler-Hammer, Inc., Milwaukee, Wis.
Johnson, J. O., chief product engineer, Aircraft-Marine Products Inc., Elizabeth, N. J.
Komives, L. I., electrical engineer, Detroit Edison Company, Detroit, Mich.
Leroy, E. R., acting vice-president in charge of engineering, Teleregister Corporation, New York.
MacGuffie, C. I., manager, industrial dept., General Electric Company, Schenectady, N. Y.
Marvin, H. B., assistant engineer, General Electric Company, Schenectady, N. Y.
McCoy, R. L., chief design engineer, Locke Insulator Corporation, Baltimore, Md.
Moore, R. C., electrical engineer, Allis-Chalmers Manufacturing Company, West Allis, Wis.
Rayner, R. L., transmision maintenance engineer, Michigan Bell Telephone Company, Detroit, Mich.
Sellers, J. F., engineer in charge of d-c engineering, electrical department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Shepherd, V. V., electrical engineer, General Electric Company, Schenectady, N. Y.
Sillers, T. G. A., assistant engineer, in charge, switchgear division, Allis-Chalmers Manufacturing Company, W. Allis, Wis.
Smith, W. C., engineer of foreign wire relations, Michigan Bell Telephone Company, Detroit, Mich.
Snell, D. S., electrical engineer, General Electric Company, Schenectady, N. Y.
Thiermann, A. H., control engineer, Virginia Electric and Power Company, Richmond, Va.
Thomas, D. E. F., senior research engineer, Detroit Edison Company, Detroit, Mich.
Warren, H. S., Phoenix-Arizona manager, Westinghouse Electric and Manufacturing Company, Phoenix, Ariz.
Weber, E., consulting engineer, Denver, Colo.
Welman, G., chief electrical inspector, Louisiana Rating and Fire Prevention Bureau, New Orleans, La.
Winn, L., chief of substation, Memphis Light, Gas and Water Division, Memphis, Tenn.
Woodward, J. S., electrical design engineer, General Electric Company, Schenectady, N. Y.

Wright, J. D., manager industrial engineering department, General Electric Company, Schenectady, N. Y.

Zimmerer, C. W., assistant electrical engineer, Underwriters Laboratories, Inc., New York

35 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. Any member objecting to the election of any of these candidates should so inform the national secretary before June 30, 1943, or August 31, 1943, if the applicant resides outside of the United States or Canada.

To Grade of Member

Bullied, J. S., Capitol Elec. Co., San Diego, Cal.
Cannedy, R. E., Arthur McKee & Co., Cleveland, O.
Cockerline, H. B., Oregon State College, Corvallis, Oreg.
Cole, L. W., Cole Elec. Prod. Co., Inc., L. I. City, N. Y.
Cummings, B., Ill. Bell Tel. Co., Chicago, Ill.
Dace, F. E. (Member re-election), Bradley Polytechnic Inst., Peoria, Ill.
Denny, W. M., Gen. Elec. Co., Schenectady, N. Y.
Dewar, H. D., Gibbs and Hill, Inc., New York, N. Y.
Henry, P., Leach Relay Co., Los Angeles, Cal.
Hough, A. L., Shawinigan Water and Pr. Co., Montreal, Canada.
Howlett, P. W. (Member re-election), Sangamo Co., Montreal, Canada.
Jenks, D. W., Gen. Elec. Co., Schenectady, N. Y.
Johnson, R. E., Gen. Elec. Co., Los Angeles, Cal.
Joy, H. M., Master Elec. Co., Dayton, O.
Knight, J. B., Jr., U. S. Navy, Port Trumbull, New London, Conn.
Mack, E. A., Consult. Engr., Huntington, W. Va.
Mann, W. J., Jr. (Member re-election), Wolfe & Mann Mfg. Co., Baltimore, Md.
Martin, D., J. H. Bunnell & Co., Brooklyn, N. Y.
Mc Nutt, W. H., W. E. & M. Co., Cincinnati, O.
Mohler, F., Gen. Elec. Co., Schenectady, N. Y.
Orth, R. F., Johns-Manville Sales Corp., New York, N. Y.
Parker, W. A. H. (Member re-election), Craven House, Kingsway, London, England.
Peters, J. R. (Member re-election), City of Seattle Dept. of Lt., Seattle, Wash.
Poliquin, A. J., Master Elec. Co., Dayton, O.
Raft, J. S., Rafn-Morgan Elec. Co., Billings, Mont.
Smith, J. E., Kelso Wagner Co., Dayton, O.
Smith, R. P. (Member re-election), Westinghouse Elec. Supply Co., Atlanta, Ga.
Trone, D. (Member re-election), Internatl. Gen. Elec. Co., Schenectady, N. Y.
Varley, P., Canadian Industries, Ltd., Montreal, Canada.
Vellines, W. E., Jr., Chesapeake & Potomac Tel. Co., Charleston, W. Va.
Watson, H. E. (Member re-election), Gen. Elec. Co., Cincinnati, O.
Zimmerman, N. W. F., American Cyanamid Co., Bound Brook, N. J.

32 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Brewer, G. R., M.I.T., Cambridge, Mass.
Elliott, J. R., Gen. Elec. Ez-Ray Corp., Boston, Mass.
Fortenbach, J. H., Gen. Elec. Co., Schenectady, N. Y.
Greenhill, K. P., Gen. Elec. Co., Schenectady, N. Y.
Johnson, E. L., Conn. Pr. Co., New London, Conn.
Kulberg, M. E., Sylvania Elec. Products, Inc., Salem, Mass.
Losey, J. J., Gen. Elec. Co., Lynn, Mass.
Pope, A., N. E. Tel. & Tel. Co., Boston, Mass.
Scanlan, J. P., Mutual Boiler Ins. Co., Boston, Mass.
Shackelford, C. H., Gen. Elec. Co., Schenectady, N. Y.
Snyder, W. (Associate re-election), Niagara Alkali Co., Niagara Falls, N. Y.
Stauffer, L. H., Gen. Elec. Co., Schenectady, N. Y.
Vacca, R. H., Harvey Radio Labs., Inc., Cambridge, Mass.
White, M. L., W. E. & M. Co., Boston, Mass.

2. Middle Eastern

Baker, A. J., Ohio Power Co., Philo, O.
Barkley, W. J., Cons. Gas Elec. Lt. & Pr. Co., Baltimore, Md.
Boyer, C. S., Gen. Elec. Co., Philadelphia, Pa.
Brett, R. J., War Dept., Wright Field, Dayton, O.
Bryans, H. T., Philadelphia Elec. Co., Philadelphia, Pa.
Burke, D. C., Gen. Elec. Co., Philadelphia, Pa.
Campbell, C. H., Susquehanna Elec. Co., Conowingo, Md.
Carlson, J. T., Master Elec. Co., Dayton, O.
Cherones, W. J., Air Serv. Com., Patterson Fd., Fairfield, O.
Chromick, J., Frigidaire Pt. #2, Moraine, O.
Clark, L. D., Master Elec. Co., Dayton, O.
Dunn, J. W., Greenville Elec. Lt. & Pr. Co., Greenville, O.
Dunning, R. P., Graybar Elec. Co., Inc., Dayton, O.
Feldstein, S. V., Gen. Elec. Co., Philadelphia, Pa.
Hamm, G. B., Wright Field, Dayton, O.
Hayn, G. J., Gates & Shepard, Philadelphia, Pa.
Heindl, J. J., Jr., Cons. Gas & Elec. Co., Baltimore, Md.
Henry, L. H., Genl. Motors, Dayton, O.
Keel, J. J., Western Elec. Co., Baltimore, Md.
Kelley, S. B., U.S.N., Neville Is., Pittsburgh, Pa.
Killen, R. B. (Associate re-election), Dayton Pr. & Lt. Co., Dayton, O.
Lang, J. O. (Associate re-election), Dayton Pr. & Lt. Co., Dayton, O.
Major, C. B., Brown & Heim, Inc., Baltimore, Md.
Medley, E. H., Lear Avia. Inc., Piqua, O.
Milroy, P. R., Gen. Elec. Co., Erie, Pa.
Mushall, D. J., Natl. Carbon Co., Cleveland, O.
Noren, T. E., American Tel. & Tel. Co., Dayton, O.
Oxley, K. G., Dayton Pr. & Lt. Co., Dayton, O.
MacMillan, N., Natl. Cash Register Co., Dayton, O.
Marshmen, B. C., U. S. Navy, Cincinnati, O.
Menard, G. A., Gen. Elec. Co., Philadelphia, Pa.
Nelson, R. H., Westinghouse Radio Div., Baltimore, Md.
Noy, J. M. (Associate re-election), Climax Molybdenum Co., Langeloth, Pa.
Parsons, H. S., Whiteley Elec. Co., Baltimore, Md.
Peirce, C., War Dept. Wright Field, Dayton, O.
Pottle, C. J., Frigidaire Pt. #2, Dayton, O.
Puterbaugh, W. H., Jr., Natl. Cash Register Co., Centerville, O.
Rappaport, H., Penn. R.R., Harrisburg, Pa.
Schindler, H. J., War Dept., Wright Field, Dayton, O.
Springle, P., Frigidaire Pt. #2, Dayton, O.
Squibb, R. W., American Rolling Mill Co., Zanesville, O.
Surber, W. H., Jr., Princeton Univ., Princeton, N. J.
Teszeo, J. C., Navy Dept. Bureau of Ships, Washington, D. C.
Unger, J. J., Elect. Prod. Co., Cleveland, O.
Vaughn, H. R., Line Material Co., Zanesville, O.
Warner, M., Dravo Corp., Wilmington, Del.
Weddell, J. A. (Associate re-election), Goodyear Tire & Rubber Co., Akron, O.
Wojcik, H. L., Air Serv. Com., Patterson Fd., Dayton, O.
Yetter, J. W., Gen. Elec. Co., Philadelphia, Pa.

3. New York City

Adams, L. F., U. S. Navy Yard, Brooklyn, N. Y.
Anderson, R. I., Sperry Gyroscope Co., Inc., Brooklyn, N. Y.
Bachman, C. V., Orange & Rockland Elec. Co., Monsey, N. Y.
Bank, H. M., 754 Lexington Ave., Brooklyn, N. Y.
Blanchard, T. G., Bell Tel. Co., Inc., New York, N. Y.
Carman, R. C., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Doyle, P. W. (Associate re-election), Cox & Stevens, Inc., New York, N. Y.
Emerson, J. A., Burns & Roe, New York, N. Y.
Green, J. B. P., Abbott Merkt & Co., New York, N. Y.
Havlock, F. B., Gage Publishing Co., New York, N. Y.
Hliddal, T., I. T. & T. Corp., New York, N. Y.
Hoffmann, J. C., Forstmann Woolen Co., Passaic, N. J.
Kandel, E., Kandel Bros., Middletown, N. Y.
Kerner, G. H., Western Elec. Co., Kearny, N. J.
Klemantowitz, W., Western Elec. Co., New York, N. Y.
Koch, R. H., J. G. White Engr. Corp., New York, N. Y.
Lake, R. E., Pratt Inst., Brooklyn, N. Y.
LoMedico, T., J. G. Sharp, New York, N. Y.
O'Hara, T. P., U. S. Navy Yard, Brooklyn, N. Y.
Patrone, E. F., U. S. Navy Yard, N. Y.
Powell, F. T., U. S. Rubber Co., Passaic, N. J.
Proctor, R., Proctor Elec. Co., Asbury Park, N. J.
Rabinovitch, V. S., Mining Equipment Corp., New York, N. Y.
Reber, J. F. (Associate re-election), Chemical Const. Corp., New York, N. Y.
Ryan, E. H., U. S. Govt., Navy Dept., Navy Yard, N. Y.
Ryan, J. R. C., Techno Scientific Co., Yonkers, N. Y.
Stuart, W. T., McGraw-Hill Pub. Co., New York, N. Y.

4. Southern

Emmons, P. A., Jr., Carolina Aluminum Co., Badin, N. C.
McCartney, C. B., Fla. Pr. Corp., St. Petersburg, Fla.
Raflalovich, E. V., Tenn. Valley Auth., Wilson Dam, Ala.
Roberts, W. F., Tenn. Valley Auth., Chattanooga, Tenn.

5. Great Lakes

Beach, G. H., Commonwealth Edison Co., Chicago, Ind.
Cassidy, C. F. (Associate re-election), Gen. Elec. Co., Chicago, Ill.
Hurst, E. H., Hartford Steam Boiler Inspection & Ins. Co., Detroit, Mich.
McNeill, E. H., The Okonite Co., Chicago, Ill.
Petry, H., Engr., Rushville, Ind.
Rachford, J. K., E. I. DuPont & Co., Charlestown, Ind.
Schmitz, N. L., Cutler-Hammer, Inc., Milwaukee, Wis.
Vanderbeek, R. O., H. A. Douglas Mfg. Co., Bronson, Mich.

7. South West

Anderson, R. L., Lower Col. River Auth., Austin, Tex.
Brown, F. W., Kansas Gas and Elec. Co., Wichita, Kans.
Coate, L. W., Butler Mfg. Co., Kansas City, Mo.
Harris, H. W., University of Mo., Columbia, Mo.
Horn, R. T., St. Joseph Pr. & Ltg. Co., St. Joseph, Mo.
Haynes, C. M., Empire Dist. Elec. Co., Baxter Springs, Kans.
Oliver, W. H., A. T. & T. Co., St. Louis, Mo.
Shriver, W. B., W. E. & M. Co., Houston, Tex.

8. Pacific

Gagnier, C. E. (Associate re-election), No. Amer. Avia., Inc., Inglewood, Cal.
Gindron, F. H., Elec. Engg. & Mfg. Corp., Los Angeles, Cal.
Glaze, L. B., No. Amer. Avia., Inc., Inglewood, Cal.
Gragg, W. C., Goodyear Aircraft Corp., Litchfield Park, Ariz.
Grane, M. M., U. S. Navy, San Francisco, Cal.
Hanna, H. F., Pac. Naval Air Bases, Alameda, Cal.
Holley, C. C., Aluminum Co. of America, Los Angeles, Cal.
Johnston, B. W., Douglas Aircraft Co., Santa Monica, Cal.
King, S. C., Douglas Aircraft Co., Santa Monica, Cal.
Mangum, O. K., U. S. Bur. of Reclamation, Phoenix, Ariz.
Maurice, G., Elec. Engg. & Mfg. Corp., Los Angeles, Cal.
McEntee, L. C. (Associate re-election), Consolidated Aircraft, San Diego, Cal.
McMullin, E. K., No. Amer. Aviation, Inc., Inglewood, Cal.
Moriarty, A. F., Central Arizona Lt. & Pr. Co., Phoenix, Ariz
Morris, F. W., Southern Cal. Edison Co., Los Angeles, Cal.
Nash, A. W., Douglas Aircraft Co., El Segundo, Cal.
Nothmann, R. S., Sawyer Elect. Mfg. Co., Los Angeles, Cal.
Payse, V., Jr., No. Amer. Avia., Inc., Inglewood, Cal.
Phillips, E. C., Coast Elec. Co., San Diego, Cal.
Piper, R. I., Southern Cal. Tel. Co., Los Angeles, Cal.
Rogers, S., Dr. Lee de Forest, Hollywood, Cal.
Russell, W. A., Jr., Douglas Aircraft Co., Santa Monica, Cal.
Seibert, R. C., Cutler-Hammer Co., Los Angeles, Cal.
Shinn, G. C., Roosevelt Base, Terminal Island, Cal.
Strader, M., Jr., Aluminum Co. of America, Torrance, Cal.
Strauss, F. E., Gen. Elec. Co., San Francisco, Cal.
Taylor, D. H., Douglas Aircraft Co., Los Angeles, Cal.
Yates, C. T., Cent. Arizona Lt. & Pr. Co., Phoenix, Ariz.

9. North West

Applegate, W. A., U. S. Army Engrs., Portland, Ore.
Ball, R. M., Montana Pr. Co., Butte, Mont.
Benson, L. B., Anaconda Wire & Cable Co., Seattle, Wash.
Carte, W. A., Siems Drake Puget Sound Co., Seattle Wash.
Converse, W. H., Jr., Siems Drake Puget Sound Co. Seattle, Wash.
Fahlstrom, M. E., Diablo Pr. Plant, Rockport, Wash.
Hudson, H. M. (Associate re-election), Harold M. Hudson Co., Seattle, Wash.
Klaunig, W. E. J., Associated Shipyards, Seattle, Wash.
Moxley, W. J., Puget Sound Pr. & Lt. Co., Seattle, Wash.
Rydell, R. W., Spokane Army Depot, Spokane, Wash.
Scofield, E. E., Washington Water Pr. Co., Spokane, Wash.
Temple, R. B. (Associate re-election), Gen. Elec. Co., Portland, Ore.
Walker, R. A., Puget Sound Pr. & Lt. Co., Seattle, Wash.

10. Canada

Hastings, A. S., Canadian Comstock Co., Montreal, Canada.
Kirlin, G. (Associate re-election) Canada Wire and Cable Co., Montreal, Canada.
Morden, W. E., Phillips Elec. Works, Ltd., Brockville, Ont.
Walters, W. H., Northern Elec. Co., Ltd., Montreal, Canada.

Elsewhere

Rabay, A. N., Gen. Elec. Co., S/A, Rio de Janeiro, Brazil.
Simmons, H. G., Distributing Dept. Elect. Board, Trinidad, B. W. I.
Valdes, J. L., Westinghouse Elec. Intl. Co., Santiago, Chile.
O'Bourke, W. G., Cable & Wireless West Indies Ltd., Havana, Cuba.
Pennig, O. D., Gen. Elec. Co., Ltd., Witton, Birmingham, England.
Meeks, C. A. L., Westmorland & Dist. Elec. Supply Co., Ltd., Carnforth, Lancashire, England.
Stewart, R. H., English Elect. Co., Ltd., Stafford, England.
Sidhu, H. S., Indian Inst. of Sciences, Bangalore, India.

Total to grade of Associate
United States and Canada, 155
Elsewhere, 8

OF CURRENT INTEREST

Foreign Patents Offered to U. S. Industry

Putting the patents formerly vested in enemy nationals or nationals of enemy-occupied countries to work for the United Nations war effort, is the major task yet to be accomplished in combating the economic penetration of American industry by enemy interests, according to a recent report by the Office of the Alien Property Custodian and the Treasury Department who are charged with the handling and disposal of enemy property.

A number of small firms have been able through patent licenses obtained from the Custodian to convert their plants to war production. Some of the products and processes covered in these conversions are collapsible boats for the Navy, fire-fighting materials, machining crankshafts, materials used in dressing ores, manufacture of alumina for airplanes, and heat-treating facilities for metal working.

The patents in use, however, represent but a small part of the 41,077 patents and pending patent applications covering inventions in every field of applied science, which have been vested and are under the control of the Custodian. These patents symbolize the expenditure of millions of dollars and millions of man-hours of research by the finest scientific minds of countries under Axis domination. They cover some of the latest achievements in the production of dyestuffs, plastics, pharmaceuticals, electrical goods, and textiles. Many patents on processes that have enabled the enemy to carry on mechanized warfare while cut off from petroleum, rubber, and other raw materials are included. The figures released by the Custodian reveal the proportion of patents in different fields: 1,282 are in the field of ordnance and aeronautics, 25,423 are related to manufacture, transportation, power, and machinery, 6,647 are chemical in nature, 836 metallurgical, and 6,889 electrical.

As indicative of the importance such patents could assume in the national economy, the office of the custodian listed some of the American companies whose progress has been aided by German patents seized during World War I. In the last war patents vested from the enemy were licensed to producers on an exclusive basis. However, at present the government is following a policy designed to make the scientific advances latent in the patents more generally felt in American industry as a whole. As many industrial producers as possess the means of employing a patented device may obtain a patent license on a nonexclusive basis, and royalty-free terms.

Patents which have been vested from the nationals of enemy-occupied countries will be licensed on the same non-exclusive, royalty-free basis except that the license expires six months after the war ends. At present the government is negotiating the question of the royalties on such patents with the governments in exile of the countries involved.

The Office of the Alien Property Custodian has issued the following simplified outline of the procedure to be followed by those interested in securing licenses to any of the vested patents:

1. Write to the Office of the Alien Property Custodian, Chicago, Ill., for an Index of Patents vested in the Alien Property Custodian.

2. Write to the same address for classified lists of vested patents and patent applications in which you are interested. All classes are sold for ten cents each, except nine classes which are 25 cents each.

3. Printed copies of vested patents and drawings and specifications of vested patent applications may be secured from the Commissioner of Patents, Washington, D. C., for ten cents each.

4. Send to the Office of Alien Property Custodian, Washington, D. C., your letter of application for a license to use a vested patent. Application fee of $50, plus $5 for each related patent to be covered in one license should accompany application.

WPB Production Clinic Program Described at District Meeting

Reviewing the success of the program of co-operation among industrial operators through problem clinics inaugurated by the War Production Board, T. M. Linville (M '34), Schenectady Section Secretary, in a paper presented at the North Eastern District Technical Meeting, Pittsfield, Mass., on April 8, covered the arrangements made by WPB for financial and other assistance, local arrangements and program topics, and the organization of the Schenectady clinic. He emphasized the fact that, while normal industrial progress requires competition, war production benefits from co-operation.

At the outset of the program the WPB decided to work through the national engineering societies to effect an exchange of experience that would make available to all operators the best solution to specific production problems. The co-operating national societies were: the American Society of Mechanical Engineers, the Society of Automotive Engineers, the American Institute of Chemical Engineers, the American Society of Civil Engineers, the American Institute of Electrical Engineers, and the American Institute of Mining and Metallurgical Engineers. The engineering societies were selected as best fitted for the work although they would be acting for nonmembers more often than for their own members.

Under the terms of the contract outlined by Mr. Linville, the normal budget of a clinic is $200. This cost is borne by the WPB. Any dinners or luncheons connected with the clinics are self-sustaining. Program subjects must adhere strictly to shop talk about production methods and problems. Topics chiefly administrative, war contracts, priority difficulties, labor relations are not to be discussed. WPB and the Office of War Information assist with publicity. In addition Mr. Linville mentioned a pamphlet, "Suggestions for Organization and Conduct of War Production Conferences," published by WPB which gives a synopsis of the duties of the essential committees. Any one national society or group of societies may propose a clinic. A WPB representative will then visit the city chosen for the clinic to act as liaison agent.

From his experience in organizing the recent Schenectady, N. Y., clinic (*see page 265*), Mr. Linville recommended that the national societies organize panels separately. However he stated that the broadest possible sponsorship pays the highest dividends in attendance and interest if responsibility can be properly allocated. Besides a discussion leader, several panel members are needed for each session. The latter should be prepared to present problems for about ten minutes each and should possess wide experience in the subject discussed.

Attendance, which Mr. Linville believes is the surest measure of success, has varied from 500 to 2,500 at the clinics already held in 19 of the 37 cities picked by the WPB, since the first one at Newark, N. J. (*EE, July '43, pp. 382–3*). As illustrative of the direction of interest at the clinics, Mr. Linville cited the sessions best attended at representative clinics. These were: electrical problems and accident prevention at Philadelphia, Pa., maintenance and machine-shop problems at Indianapolis, Ind., selection and training of employees and product inspection at Hartford, Conn., women in industry and electric-power machinery at Providence, R. I., machine-shop problems and getting the most out of cutting tools by welding and brazing, protective metal coatings, and problems in drilling and tapping at Chicago, Ill.

In conclusion Mr. Linville expressed his belief in the practical value of the team spirit engendered by industrial operators meeting with others faced with problems similar to their own.

Navy Offers Commissions to Electronic Specialists

Some of the billets for Naval officers trained in electrical engineering (*EE, Feb. '43, p. 81*) created by the rapid expansion in the number of vessels serviced by ultra-high frequency apparatus are still to be filled according to a recent release from the Office of Naval Procurement.

Men who hold degrees in electrical engineering or men with degrees in mathe-

matics, physics, or other branches of engineering who have acquired a sound working knowledge of a-c circuits and electronics may apply for commissions. As previously reported those accepted will be given the Navy's three-months' course in ultrahigh frequencies.

Applications for the commissions are being received at local offices of Naval Officer Procurement in the following cities throughout the United States:

Atlanta, Ga.	New Orleans, La.
Charleston, S. C.	Birmingham, Ala.
Columbia, S. C.	Dallas, Tex.
Jacksonville, Fla.	Houston, Tex.
Raleigh, N. C.	Memphis, Tenn.
Boston, Mass.	Nashville, Tenn.
Chicago, Ill.	Oklahoma City, Okla.
Cincinnati, Ohio	New York, N. Y.
Cleveland, Ohio	Rochester, N. Y.
Des Moines, Iowa	Philadelphia, Pa.
Detroit, Mich.	Pittsburgh, Pa.
Kansas City, Mo.	Richmond, Va.
Milwaukee, Wis.	Charleston, W. Va.
Minneapolis, Minn.	Norfolk, Va.
St. Louis, Mo.	San Francisco, Calif.
Los Angeles, Calif.	Seattle, Wash.
Phoenix, Ariz.	Portland, Oreg.
San Diego, Calif.	Washington, D. C.
Miami, Fla.	Baltimore, Md.

Planning Board Formed by Radio Industry

That a Radio Technical Planning Board which will chart the postwar course of frequency modulation, television, and other recent advances in radio has been formed by the Radio Manufacturers Association and the Institute of Radio Engineers with the co-operation of the Federal Communication Commission, was announced by FCC Chairman J. L. Fly at the recent annual meeting of the National Association of Broadcasters in Chicago, Ill.

The Board, which has a scope similar to that of the prewar National Television System Committee, will seek to avoid delay in passing on the recent technical developments in radio to the public after the war. By proper allocation of operating frequency and systems standardization the chaos which existed in the early nineteen twenties will not be repeated.

The Board will function through a chairman appointed by the presidents of the RMA and the IRE with the approval of the FCC, and members appointed by the Chairmen, representing recognized radio groups, and the chairmen of the panels. These panels will do the research necessary to formulate recommendations for government agencies and industrial and professional organizations. Panel membership will be appointed by the panel chairmen who will be appointed by the Board chairman. At present, panels on allocation, spectrum utilization, high frequency generation, television and facsimile, direction finding and location, industrial, medical, and scientific equipment, standard broadcasting, relay systems, and radio communication are contemplated. Government representatives may attend the sessions of the board or the panels but they are not entitled to vote on any matter under consideration. Additional panels will be formed as they are needed.

The project is being financed by the RMA and an appropriation of $10,000 has already been made to defray RTPB expenses.

Capacitors Raise Transmission Capacity and Save Metals

Experimenting with a midget power line, R. D. Evans (F '40) consulting transmission engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., recently demonstrated a method of increasing the capacity of a transmission system by means of thousands of small capacitor units distributed along the line.

A comparison of costs based on Mr. Evans' estimates shows the savings that might result from the use of this method to increase the capacity of a typical line. The cost of increasing the capacity of a 250-mile-long power line 65 per cent by an additional transmission line plus auxiliary equipment would be about $4,500,000. By installing 7,200 capacitors instead, the same results can be attained for $1,200,000. The cost of a generator needed in both instances is not included in these appraisals.

Substituting the capacitor units for extra transmission wires also conserves the more essential metals, Mr. Evans pointed out. While 7,200 capacitors can be built from nine tons of copper and brass, 175 tons of steel, and a few tons of aluminum, extra power lines would require 2,900 tons of copper and 7,600 tons of steel.

The new device which secures the capacitors in steel structures beneath the power line was made practicable by a recently developed protective system in which switches automatically cut off the bank of capacitors from a circuit when a short circuit occurs. Service is again automatically restored when the trouble is removed. Mr. Evans collaborated with A. C. Monteith (M '40) and R. E. Marbury (M '36) in developing this protective system.

Mica Supply Still Barely Adequate

Although immediate erection of a plant which will produce "Polectron," synthetic substitute for mica, has been announced by the General Aniline and Film Corporation, New York, N. Y., the mica-graphite division of the War Production Board has issued a warning that no end to the heavy drain on the critically low stock of high-grade mica may be expected.

The Board pointed out that none of the new materials now in process of development can be used as an all-around substitute for mica. In addition there has been little actual adoption either by the armed services or by prime contractors of components containing any of these new materials as a replacement for mica. Even when estimates on the percentage of substitution that now seems probable in the near future are taken into account the remaining requirements of war industries will absorb all anticipated mica production.

The Aniline corporation's product "Polectron" combines high temperature resistance with low dielectric loss which make it useful in several types of radio equipment now requiring mica. Polectron can be employed in the production of electronic apparatus without fundamental change in machines or methods of manufacture. One ton of "Polectron" fabricated into mica replacement material will save from 10 to 15 tons of imported block mica which often must be flown from India or Brazil.

Government Has $7,000,000,000 Invested in War Plants

The $7,000,000,000 which the United States Government has invested in 1,479 war plants portends an extensive government interest in postwar industry, Secretary of Commerce Jesse Jones indicated in an Army Day address delivered at New York.

According to Mr. Jones the Defense Plant Corporation, a subsidiary of the Reconstruction Finance Corporation, has financed 54 plants for radio and radio equipment with an investment of $60,000,000. Other plants so subsidized are 51 airplane plants, 344 plants for making airplane parts, 64 air school plants, 70 ordnance plants, 161 plants for manufacturing tools, and 43 plants for aluminum manufacture. Investment in plants for airplanes and parts, instruments and accessories, totaled $2,640,000,000 while the total investment for guns, ammunition, tanks, and armor was $440,000,000.

In Mr. Jones's opinion the government should neither own nor operate the facilities it has constructed but should expect to work with private industry in operating these plants.

Automatic Control Sights Antiaircraft Guns

A mechanical brain that will sight an antiaircraft gun automatically, accurately, and instantly is being developed by the engineers of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. The distance to the target, its rate of speed, its direction of travel up or down, the amount of windage, the force of gravity, the gunner's own speed and direction if any, all hitherto separate computations will be part of one automatic operation.

Instruments will provide the gun operator with the actual angular position of a nearby radio antenna recording the foregoing facts. This antenna either remains fixed in position, rotates continuously at speeds varying from one revolution per minute to one every six hours, or swings back and forth through a selected arc at a chosen speed.

The controls and drive will work accurately even when wind velocities rise to 125 miles per hour, and temperatures fall far below zero.

The heavy gun turret which turns slowly if hand-propelled swings by electric power under the new control scheme. Some older type guns can be corrected to the sighting mechanism by a hydraulic torque amplifier or oil-driven gear.

Chinese Engineers to Study American Techniques

Under a program developed jointly by the National Resources Commission of China and the Board of Economic Warfare, 32 young Chinese engineers have arrived in the United States to study American engineering techniques which they intend to employ in rebuilding China, the Board announced recently.

The engineers expect to remain two years working in their major fields of interest. Eight of the group who expressed interest in electric power generation and transmission have taken positions with the Tennessee Valley Authority. Others are studying production of electrical equipment, mechanical and chemical engineering, metallurgy, mining, petroleum, and industrial management with privately owned industrial firms.

The young men selected for the training program received advanced training in Chinese technical schools and possess several years of actual experience in their chosen fields. Since the industries to which they have been assigned are engaged in war work, the men are first accredited by the United States Army. They are paid by the National Resources Commission of China. The program was first sponsored by the Division of Cultural Relations of the United States Department of State.

Conservation Division of WPB Reorganized

In order to establish a parallel relationship between the conservation of materials and the conservation of products manufactured from these materials, the Conservation Division of the War Production Board has been reorganized into two main branches, materials and products, Howard Coonley, director of the Division has announced.

Material substitution, product specification, and product simplification, which are the three main objects of the division, will cut across the work of the two major branches. This will result in greater coordination of the assistance given to the Division by its consultants. The latter will be called upon for advice on both materials and related products when industrial production planning is undertaken.

Each consultant will continue to be responsible for conservation planning within a specific field of industry. Two-thirds of these consultants are technical specialists. Before the war, 36 of them were professional engineers, 12 were chemists, while others were metallurgists, architects or industrial engineers. The average span of specialized experience among them is 20 years.

Radio Parts Now Soldered By Electronic Heat

Electronic high-frequency induction heat will control some of the difficulties inherent in employing gas heat in soldering the crystal units which maintain frequency in war-radio equipment, J. E. Jordan (A '42), engineer, General Electric Company, Schenectady, N. Y., recently explained.

When gas heat is used to solder the metal shield for the crystal units, there is an ever-present danger of distortion resulting from the slow heat's being conducted to the crystal, he pointed out. Injurious effects may also result from the products of high-temperature gas combustion.

Under the new process, Mr. Jordan disclosed, the crystal unit is placed in a fixture adjacent to a two-turn inductor coil and a perforated air-blast ring nozzle. Heat and a cooling air blast alternately reach the metal of the unit for a few seconds at a time. The entire sequence is automatically timed to assure uniform seals. During the heating cycle the operator twists the shell slightly to distribute the solder.

ASA Completes Standard for Radio Parts

In order that home radio sets may be serviced with the least possible employment of scarce materials essential to the war effort, the American Standards Association has issued a war standard for radio parts entitled, "Power and Audio

Future Meetings of Other Societies

American Association for the Advancement of Science. June 14–19, 1943, Corvallis, Oreg.

American Mathematical Society. June 16–17, 1943, Corvallis, Oreg.

American Chemical Society. September 6–10, 1943, Minneapolis, Minn.

American Institute of Mining and Metallurgical Engineers. Joint fuels conference, October 28–29, 1943, Pittsburgh, Pa.

American Society for Metals. Annual convention, October 18–22, 1943, Chicago, Ill.

American Society of Heating and Ventilating Engineers. Semiannual meeting, June 6–7, 1943, Pittsburgh, Pa.

American Society of Mechanical Engineers. Semiannual meeting, June 14–16, 1943, Los Angeles, Calif.

American Society for Testing Materials. Annual meeting, June 28–July 2, 1943, Pittsburgh, Pa.

American Society of Refrigerating Engineers. 30th spring meeting, June 1–3, 1943, Cleveland, Ohio.

Canadian Electrical Association. Annual meeting, June 17–18, 1943, Quebec, Que.

Edison Electric Institute. Annual meeting, June 2–4, 1943, New York, N. Y.

Illuminating Engineering Society. Great Lakes regional conference, June 5, 1943, Detroit, Mich.; northeastern regional conference, June 11, 1943, New York, N. Y.

Society for the Promotion of Engineering Education. Annual meeting, June 18–20, 1943, Chicago, Ill.

Society of Automotive Engineers. Diesel engine, fuels, and lubricants meeting, June 2–3, 1943, Cleveland, Ohio.

Oil Used in Impregnating Condenser Bushing

These men are spiral-winding a large impregnated condenser bushing with paper and copper foil. The paper used in this process was formerly impregnated with shellac imported from India. By using oil instead the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., saves 144,000 pounds of shellac annually. Tests have shown that electrical qualities of the new bushing, particularly the power factor, are superior to older types

Transformers and Reactors, Home Receiver Replacement Type." The standard was compiled at the request of the Office of Price Administration.

Covering the performance and quality of a simplified list of 14 such parts, the standard is expected to meet the needs of about 90 per cent of the radio sets in operation. The standard was drawn up with the intention of using a minimum of such materials as copper and transformer steel, that might be allocated to radio replacement parts. The simplified list of units will also mean fewer production lines and smaller dealer inventories.

Used Motor Unit Facilitates Production and Saves Materials

The Used Motor Unit of the War Production Board recently announced a successful first full month of operation. Of 1,515 requests for used motors and generators the unit was able to fill all but 87.

By placing idle equipment in active service in industry at large and in over 29 war agencies, the unit which was established in February has saved 400 tons of critical materials and approximately 40,000 man-hours which would have been necessary to manufacture new equipment. At present 30,000 to 35,000 pieces of idle equipment are listed, and requirements for general-purpose standard types of second-hand motors can be filled quickly. However owners of idle equipment are urged to register it immediately.

Tantalum Mined in New Mexico. With the recent discovery of tantalum ore in New Mexico, manufacturers of special carbides and electrical equipment may anticipate an increased supply of that rare material, the United States Bureau of Mines has announced. By experimenting with 30 tons of ore from which over three tons of high-grade concentrate were extracted, the Bureau has worked out a treatment process in detail in its pilot plant at Rolla, Mo. The concentrate which is stockpiled at Rolla has been priced at $3.50 a pound or $7,000 a ton by the Metals Reserve Company, a federal agency, which has undertaken disposal of the mineral.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

The Anniversary of a Symbol

To the Editor:

It has been brought out everywhere that the year of turmoil, 1942, marked the 60th anniversary of Edison's Pearl Street power house and that of the first transmission line. But no mention was made that the same year marked the 50th anniversary of the introduction of the square root of minus one into electrical engineering by two young American engineers, as recorded casually in *Electrical Engineering*, December 1942.

Perhaps the introduction of the $x+jy$ will eventually be considered more important than the other two, or at least as important. When we analyze the importance of inventions in the development of the electrical industry, which means practically all industry, we must give the analytical invention at least equal credit with that of physical invention. Would electrical engineering be what it is today without Maxwell or Heaviside? Would we have radio if Maxwell had not laid the mathematical foundation for it? Would the art of transmission and interconnection engineering be where it is today if Bedell and Crehore had not introduced the square root of minus one back in 1892? In this period of racial-superiority talk by others, it is interesting to note that a-c engineering is practically all American. It is also interesting to note that the two young American engineers who introduced the $x+jy$ did so as a matter of course, without proclaiming from the house tops that America is the source of all science. They did it with the modesty common to all young American engineers, inventors, and scientists. This very resourcefulness, unlimited, is our greatest hope in the war. Even now, in a new paper published in the December 1942 issue of *Electrical Engineering*, Professor Bedell, very modestly, gives the fact a mere mention that he and his colleague practically created modern a-c engineering. He quotes from a mimeographed paper presented May 8, 1934, before the Los Angeles Section of the AIEE by P. H. Nunn:

"In 1890 alternating current was just plain freak; it did not follow Ohm's law and 'clogged' itself in its circuits. Bedell and Crehore had doped out its laws and demonstrated their concepts in 100 pages of solid calculus."

Again he shows his great modesty by reporting that the $\sqrt{-1}$ has been used in astronomy back in 1797 and proceeds with his modesty by saying:

"It is to A. E. Kennelly, however, that credit should be given for bringing out its full significance in the application of complex quantities to a-c problems and to C. P. Steinmetz for so ably extending its usefulness."

The fact remains nevertheless that Bedell and Crehore invented it for the electrical engineer. It would be well for the young electrical engineer to stop for a moment and think where he would be without the $x+jy$. Our hats are off to Bedell and Crehore, the great, modest, competent, American pioneers, and many happy returns to them!

M. M. SAMUELS (F'24)

(Chief, technical standards division, Rural Electrification Administration, St. Louis, Mo.)

Inventions, Patents, and the Engineer

To the Editor:

In his most interesting contribution to the discussion of "Inventions, Patents, and the Engineer," Ford W. Harris gives expression to a sentiment that I feel sure he will want to revise after due consideration. He says:

"We can admit that the desire for profit is low and ignoble."

Although he modifies this statement somewhat by the unquoted part of the sentence, the impression is left that "the results produced up to date, etc.," were engendered by ignoble motives. That, of course is not true.

The notion that "profit" is ignoble is a relic of the false notion that in any business transaction the seller gains and the purchaser loses. If that were true, every purchaser would progressively grow poorer and poorer until all buainess would cease. The truth is just the reverse. Profit is the result of enterprise which benefits others as well as the enterpriser.

For example: Electrical rates have been decreasing almost continuously since the beginnings of the electrical industry. At first electric energy was used almost exclusively for lighting, and consequently the rates were high, necessarily so. Here in Madison 33 years ago a kilowatt-hour of electric energy cost 16 cents. As the uses of electric energy increased, and as the means of its production was improved, the rates dropped until today a kilowatt-hour costs only a trifle more than two cents. Profits made this reduction in rates, extension of service, and improvement in service possible. Again the first tungsten lamp cost me two dollars, and today I can buy a better lamp, even in a drug store, for from 10 to 15 cents. This reduction in price and improvement in the article was engendered by profits and not ignoble motives. Without profits there would be no electrical industry, and everyone would be the poorer.

TVA is a nonprofit enterprise. That is, its stockholders, the taxpayers, have received no dividends. Does that fact make TVA's motives more noble than those of

the Consolidated Edison Company which pays dividends and millions of dollars in taxes?

C. M. JANSKY (F '32)

(Professor emeritus of electrical engineering, University of Wisconsin, Madison, Wis.)

100,000,000-Volt X-Ray Machine

This large electron accelerator which will weigh 130 tons when completed will generate X rays at voltages up to 100,000,000, making possible the examination of thicker metal sections than previously could be studied by X rays. The picture shows the lower part of the huge a-c magnet, made of slabs of steel spaced apart for cooling, and consisting of thin sheets cemented together. Examining one of the circular magnet pole faces, between which the electrons are whirled around in a six-foot doughnut-shaped glass vacuum tube are (left to right) Rudolph Wroblewski, who is assisting in the erection of the device, and W. F. Westendorp (A '35) and Ernest E. Charlton of the laboratory's X-ray section

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Economy Loading of Power Plants and Electric Systems. By M. J. Steinberg and T. H. Smith. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 203 pages, illustrations, etc., 9½ by 6 inches, cloth, $3.50. (ESL).

The problem of allocation of load to power plants and to the equipment within them so as to produce electricity at the lowest cost consistent with continuity of service has become important as large electric systems have been interconnected. In this book the problem is discussed in detail. The underlying theory of economy loading is explained, the mathematical conditions for obtaining maximum efficiency are derived, the application of incremental rates for the solution of load-division problems is set forth, the limitations in the application of the theory are discussed, and the practical solution of load-division problems is explained. There is a bibliography.

Proteins, Amino Acids and Peptides as Ions and Dipolar Ions. (American Chemical Society Monograph Series No. 90.) By E. J. Cohn and J. T. Edsall, including chapters by J. G. Kirkwood, H. Mueller, J. L. Oncley, and G. Scatchard. Reinhold Publishing Corporation, New York, N. Y., 1943. 686 pages, illustrations, etc., 9½ by 6 inches, cloth, $13.50. (ESL).

This book is the result of many years of study of an important topic on the border line between chemistry and biology. The evidence concerning the size and shape of molecules of the amino acids, peptides, and proteins is examined, and the number and distribution of the electric charges that they bear is examined and presented with full documentation. Especially, the authors consider the implications of the charged structure of these molecules for their physical properties, and their physicochemical interaction with other molecules.

ASTM Standards on Electrical Insulating Materials. The American Society for Testing Materials, Philadelphia, Pa., 1942. 439 pages, 6 by 9, $2.50. (ESL).

This edition of an annual publication contains 18 standard methods of testing insulating materials, 25 tentative test methods, and 16 specifications for insulating materials. The test methods are grouped under varnishes, paints, lacquers, and their products, plates, tubes and rods, molded materials, mineral oils, ceramic products, insulating paper, mica products, textile materials, and conditioning. Specifications are given for paint products, molded materials, plates, tubes and rods, rubber products, and textile materials. The annual report of the committee on electrical insulating materials, and several condensed reports on significance of tests are also included.

ASTM Standards on Rubber Products. Prepared by ASTM committee D-11 on rubber products. Methods of Testing Specifications. American Society for Testing Materials, Philadelphia, Pa., 1943. 301 pages, illustrations, etc., 9 by 6 inches, paper, $1.75. (ESL).

This annual brings together the standard and tentative methods of tests and specifications for rubber products which the Society has approved, together with a useful bibliography on rubber testing, thus forming a convenient reference book for the laboratory. General methods, and special ones for hose, belting, gloves, matting, tape, latex, cements, sponge and hard rubbers, and for insulated wire and cables are given. Emergency alternate provisions for various standard specifications are included.

ASTM Standards on Electrical-Heating and Resistance Alloys. Prepared by ASTM committee B-4. American Society for Testing Materials, Philadelphia, Pa., 1942. 160 pages, $1.50 per single copy, $1.25 per copy for orders of 10 to 49 copies.

This 1942–43 issue contains twenty-three specifications and tests for electrical heating and resistance alloys as well as four relevant technical papers. Two, on thermostat materials, are reprinted from the 1941 edition. The others are devoted to electrical surge tests on contact materials and testing machines. More standards were compiled for radio tube and lamp materials than for any other single category.

Practical Marine Diesel Engineering. By L. R. Ford. 4th edition. Simmons-Boardman Publishing Corporation, New York, N. Y., 1943. 642 pages, illustrations, etc., 9½ by 6 inches, cloth, $6. (ESL).

The construction, operation, and maintenance of marine Diesel engines are explained thoroughly from the point of view of the operating engineer. The work is limited to the makes of engines that are being most used in the types of vessels now being built, especially those developed by the United States Maritime Commission. Other features are discussions of Diesel tugs, of deck and electrical machinery and of shipyard engine repairs. A chapter on license requirements is included.

Chemical Aspects of Light. By E. J. Bowen. Oxford University Press, New York, N. Y., Clarendon Press, Oxford, England, 1942. 191 pages, diagrams, etc., 9 by 5½ inches, cloth, $4. (ESL).

Readers who wish to know something of the theories of light and of its interactions with atoms and molecules, but who are not thoroughly versed in mathematics, will find this a helpful supplement to more formal treatises. Among the matters treated are atomic and molecular spectra from the chemical point of view, the interrelations of scattering, Raman and fluorescence radiations, luminescence and phosphorescence, photochemical reactions, chemiluminescence and photocells.

The American Leonardo, a Life of Samuel F. B. Morse. By C. Mabee. Alfred A. Knopf, New York, N. Y., 1943. 420 pages, index I-XV, illustrations, etc., 9½ by 6 inches, cloth, $5. (ESL).

Morse's career was outstanding in several fields. He was a portrait painter of distinction and founder of the National Academy of Design. He invented the telegraph and promoted it successfully. His life was a long, busy one, crowned with many honors. Mr. Mabee's biography, based on long study and access to family papers, gives a very satisfactory and interesting account of the man and his work, the most complete that has appeared.

Air Conditioning Analysis. By W. Goodman. The Macmillan Company, New York, N. Y., 1943. 455 pages, diagrams, etc., 9½ by 6 inches, cloth, $6. (ESL).

The aim here is to present a comprehensive unified treatment of the fundamentals of the art of changing the condition of air, without discussing such related subjects as refrigeration, air handling, and temperature control. The material presented is developed from an elementary point of view and illustrated by numerous solved problems. Psychrometric charts with co-ordinates of enthalpy and specific humidity for a wide range of temperatures are included.

Empirical Equations and Nomography. By D. S. Davis. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 200 pages, diagrams, etc., 9½ by 6 inches, cloth, $2.50. (ESL).

The first part of this book describes practical methods for correlating engineering data and deriving usable empirical formulas. The fundamental methods of rectification are explained together with new techniques for two-variable data and a method of correlation for equations with three variables. Part two gives an excellent account of the theory and construction of nomographic and line co-ordinate charts. A good bibliography is included.

Industrial Radiology. By A. St. John and H. R. Isenburger. 2nd edition. John Wiley and Sons. New York, N. Y.; Chapman and Hall, London, England, 1943. 298 pages, illustrations, etc., 9½ by 6 inches, $4. (ESL).

This book is intended to furnish in readable form authoritative information on the practical use of radiology in industry. The general principles governing the production and use of X rays and gamma rays are presented, together with the techniques suitable for important classes of industrial materials. A bibliography of over 1,300 titles is a valuable addition to the book.

Tennessee Valley Authority. By J. S. Ransmeier. Vanderbilt University Press, Nashville, Tenn., 1942. 486 pages, diagrams, etc., 9 by 5½ inches, cloth, $3. (ESL).

The aim of this study is to contribute to clarification of the problem of cost allocation when river control is undertaken for multiple purposes. The author studies the problem as presented by the Tennessee Valley Authority. The development of the program is presented, the various theories and problems of cost allocation are discussed critically, and the planning and policy examined.

ASTM Standards on Copper and Copper Alloys. The American Society for Testing Materials, Philadelphia, Pa., 1942. 376 pages, 6 by 9 inches, $2.25.

In addition to more than 85 standards this current edition contains emergency specifications and emergency alternative provisions to the standards applying to copper alloy products. These are expected to aid in expediting procurement of materials. The specifications listed cover copper and copper alloy wires for electrical conductors and non-ferrous metals used in copper alloys as well as copper and copper alloys, cast and wrought.

Mechanics of Materials. By S. G. George and E. W. Rettger, revised by E. V. Howell. 2nd edition. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 491 pages, diagrams, etc., 9½ by 6 inches, cloth, $3.75. (ESL).

A simple complete account of the essentials of the subject is provided, suitable for use as a college text, but containing more material than is usually covered in an elementary course. In this edition the sequence of chapters has been altered, rivet and column specifications have been revised, and an article has been added on the graphical solution of combined stresses.

A Course in Radio Fundamentals. By G. Grammer. American Radio Relay League, West Hartford, Conn., 1942. 103 pages, illustrations, etc., 9½ by 6½ inches, paper, 50 cents. (ESL).

This is a study guide containing examination questions and laboratory experiments which is intended to be used with the Radio Amateur's Handbook. The course is intended primarily for self instruction, but will also be of interest to teachers. The apparatus required is simple and can usually be constructed with material that the amateur has at hand.

Abridged Scientific Publications from the Kodak Research Laboratories. Volume XXIII, 1941. Eastman Kodak Company, Rochester, N. Y., 1942. 283 pages, 6½ by 9¼ inches.

This is a collection of thirty-five papers published by members of the laboratory staff in various technical journals. The papers presented here are shortened and the experiments described cover many facets of the photographic process.

PAMPHLETS • • •

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Construction, Maintenance and Repairing of Aircraft Instruments. By J. A. Gordon. Reprinted by Henry Paulson and Company, 30 South Wabash Avenue, Chicago, Ill., from the *Horological Journal*, London, England, 1943. 29 pages, no charge.

Technique of Molding Low Loss Phenolics. Bakelite Corporation, 30 East 42d Street, New York, N. Y., 1943. 16 pages, no charge.

Tube Picture Book. RCA Victor Division of the Radio Corporation of America, Harrison, New Jersey, 1943. 7 pages, 10 cents. Sale restricted to United States and Canada.

Report From the Advisory Committee on Government Questionnaires. United States Chamber of Commerce, 1615 H Street, N. W., Washington, D. C., 1943. 61 pages.

Manpower Lost. War Manpower Commission, 11 West 42d Street, New York, N. Y., 1943. 28 pages.

Absenteeism. War Production Board, Washington, D. C., 1943. 27 pages.

Controlling Absenteeism. United States Department of Labor, Washington, D. C., 1943. 57 pages, no charge.

A Study of Glaze Stresses. By William C. Bell. Ohio State University, Columbus, 1943. 28 pages, 40 cents.

The Foreman. National Association of Manufacturers, 14 West 49th Street, New York, N. Y., 1943. 16 pages, no charge for single copies; quantities at cost.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the June 1943 Supplement to Electrical Engineering—Transactions Section

The Rating of Power Transformers as Determined by the War Emergency

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Synopsis: Accurate rating of transformers is one of the most important elements in the problem of providing continuous service to the customers of the utility industry. Rather than attempt to follow a general rule for the loading of transformers it is believed that the urgency of wartime needs amply justifies the effort required to place individual ratings on each transformer bank of the utility under consideration. Experience has shown that such ratings vary widely. The transformers cover a wide range of sizes, designs, manufacturers, and periods of manufacture; with weights per kilovolt-ampere ranging from 7 to 20 pounds, excitation voltages ranging from 95 to 110 per cent, their daily load factors from 25 to 100 per cent, and their seasonal loading from 0 to 100 per cent. The consequent saving of "critical" material is self-evident when each case is considered individually.

During the war it is desirable to base station ratings on the thermal capacity of all the transformers normally available for service, rather than attempt to set up station ratings based on abnormally high emergency ratings of the remaining units after the assumed failure of one unit. It is essential that these higher station ratings be properly applied so that the danger of failure is minimized.

IN order to evaluate this program of individual transformer ratings, only dry units are considered. Since moisture accelerates the rate of insulation deterioration[1] and lowers its dielectric strength, increased ratings are not assigned to a questionable transformer until its moisture content has been reduced to a satisfactory value. Once this factor is eliminated, consideration of the other factors can be taken with greater accuracy and safety. Insulation deterioration and oil sludging are affected both by the magnitude and the duration of their temperatures. However, because of the simplicity of the rating method, it is necessary to consider only the magnitude at first. But as the load increases, the duration as well must then be taken into account if a maximum utilization of transformer capacity is to be realized. The capacity of bushings, tap changers, and other current-carrying parts must be checked since they may prove to be the limiting factor.

Such a program of calculating transformer capacities based on load cycles, ambient temperatures, manufacturer's test data, and operating conditions is a large undertaking unless the work is systematized and carried only as far as load conditions warrant. Therefore, a system has been set up wherein the ratings are progressively increased as the load increases. The more detailed computations are needed only when the load approaches the ratings based on the more general and, consequently, more conservative method of rating. This procedure reduces the amount of calculating and load supervising to a minimum.

Method Used in Rating Transformers

This progressive method of rating transformers is divided into four steps:

1. The ambient temperature.
2. The manufacturer's test data and operating conditions.
3. The thermal capacity.
4. The length of time at each hot-spot temperature.

This last step which is called the equal-life method of rating takes the variations in daily peak loads, the variation in ambient temperatures, and the hot-spot temperature cycle into consideration. Each successive step which usually results in a higher rating utilizes the data obtained from the previous step.

Increased Ratings for Oil-Insulated Self-Cooling Units Due to Ambient Temperatures Below 30 Degrees Centigrade (First Step)

The first step in rating transformers is to take advantage of the ambient temperatures lower than 30 degrees centigrade. Ratings are assigned, based on the Pittsburgh Weather Bureau average monthly temperatures over a 64-year period (see Table I). In order to take care of the deviation from the average temperature, six degrees centigrade is added to the mean values to obtain acceptable values for rating purposes. The actual daily average temperatures exceed the accepted monthly values used for rating less than 15 per cent of the time. The American Standards Association rule[2] which states that the "capacity can be increased 1 per cent for each centigrade degree the average temperature is below 30 degrees centigrade" is then applied to obtain monthly ratings. It may be noted that in Table I, column 2, the accepted ambient temperature for July is 30 degrees centigrade and for December seven degrees centigrade, which results in a 100 per cent rating for the month of July and 123 per cent rating for December.

When the banks are located indoors, the assumed ambient temperatures are increased five degrees centigrade under good ventilating conditions and ten degrees centigrade for average conditions. If the differential between indoor and outdoor temperatures exceeds ten degrees centigrade by measurement, the ventilation is usually improved. If the difference is less than ten degrees centi-

Paper 43-36, recommended by the AIEE committee on electrical machinery for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted November 13, 1942; made available for printing December 30, 1942.

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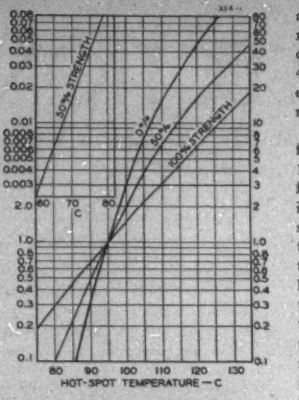


Figure 1. Life units versus hot-spot temperature for various degrees of insulation strength

One life unit equals one hour of operation at 95 degrees centigrade hot-spot temperature

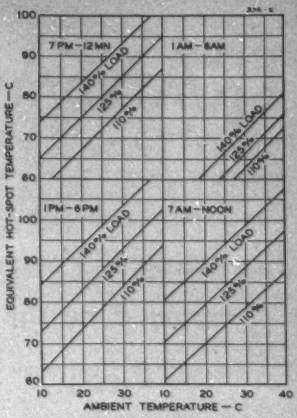


Figure 2. Illustrative equivalent hot-spot versus ambient-temperature curves for constant ambient temperatures and constant loads

grade, improvement is not usually justified.

Monthly ratings are of particular advantage in distribution substations where the lighting load is a considerable part of the total, since the shape of the seasonal load curve approximates that of the rating curve based on the outdoor ambient temperatures.

Increased Ratings of Oil-Insulated Self-Cooling Units Due to Design and Operating Conditions (Second Step)

When the load exceeds approximately 90 per cent of the rating as determined by the previous method, calculations based on the manufacturer's test data are made. In this, the losses in the transformer during the factory thermal test are calculated and compared with the actual losses in service of units built to the same specification. In determining the losses, corrections are made for the tap connections, operating temperatures, and applied voltages. In making these calculations the high- and low-voltage copper losses and the stray losses are considered separately, each being corrected to 95 degrees centigrade average copper temperature for the normal ratings. The core loss is corrected by some power of the ratio of the applied voltage to the rated voltage, the former voltage being determined from annual system voltage surveys. The exponent used is based on tests made at 100 per cent and 110 per cent excitation. If tests are not available at overexcitation, an exponent of 2.5 is suitable for most modern transformers. In the older designs this exponent ranges from 1.7 to 4.0. It must be remembered that this exponent is empirical and applies only to ratios near unity.

The temperature rises for the transformer under operating conditions at 100 per cent of rated name-plate current for the tap used are obtained by correcting the factory test values of both the hot spot over top oil and the top-oil rise by the ratio of the losses for the two conditions raised to the 0.8 power. The total losses are used for the top-oil temperature correction and the load losses for the hot-spot rise over top-oil correction. Curves of hot-spot rise over oil, hot-spot rise, and top-oil rise versus per cent load are then plotted, assuming that the rises vary as the 0.8 power of the losses as explained. (See appendix, Figure 5). This exponent is substantiated by information published in reference 3.

Before the ratings are assigned, it will be necessary to set up limiting temperatures for both the insulation and the oil. For normal ratings 105 degrees centigrade has been chosen as the limiting hot-spot temperature if the load factor is not too high. This agrees with the American Standards Association rating of 105 degrees centigrade for eight hours. The top-oil limits are set at 75 degrees centigrade for open or free-breathing transformers, 80 degrees centigrade for conservator-type units, and 85 degrees centigrade for inert gas units. These values are based mainly on experience, and the fact that sludging depends to some extent on the contact of the oil with oxygen as well as temperature and time. It is possible that these values may be revised upward if further experience justifies this action. The values chosen depend somewhat on the inspection period set up for oil reconditioning or filtering and the type of oil used.

Table I. Outdoor Ambient Temperatures

Used as a Basis for Rating Transformers
Degrees Centigrade

Month	Average Daily Temperatures*	Average Daily Temperatures +6 C	Average Daily Maximum Temperature*	Average Daily Maximum Temperature +6 C
January	0	6	4	10
February	0	6	4	10
March	5	11	10	16
April	10	16	16	22
May	17	23	22	28
June	22	28	27	33
July	24	30	29	35
August	23	29	28	34
September	19	25	25	31
October	13	19	18	24
November	6	12	11	17
December	1	7	5	11

* Based on 64-year period from 1874 to 1938, Pittsburgh Weather Bureau.

Monthly ratings can now be assigned, based on the limiting hot-spot and top-oil temperatures, the ventilation, the outdoor temperatures, and the hot-spot and oil rise versus load curves. The ambient temperatures used for this method are the average daily maximum values plus six degrees centigrade as is indicated in column 4, Table I. It will be noted that the ratings are based on ultimate temperature rise and accepted maximum hourly temperature rather than the actual temperature rise and the daily average ambient temperature. This results in a somewhat conservative rating, which does not change with load cycle and requires little office supervision. Increased ratings of considerable magnitude are possible with this method of rating; yet periodic inspection of the load cycles and close scrutiny of the ambient temperatures are not necessary.

Increased Ratings Due to Thermal Capacity (Third Step)

When the load approaches the values assigned to the units by the preceding method, it is then necessary to take advantage of the thermal capacity of the units. Load cycles for a peak winter and a peak summer day are plotted and blocked. When transformer thermal transient calculations are being made, the shape of the load cycle curve at the time

of the peak load is most important. More conservative ratings are obtained by averaging the peak load over a period of hours. For base load stations a four-hour average and for residential stations a two-hour average are about the shortest periods that should be used.

Any of the published methods of making thermal transient calculations may be used, but since curves have been prepared for the previous method of rating, advantage should be taken of this information. Load-cycle calculations for two or three assumed peak loads should be made for the winter and summer cycles, using the step-by-step method. The assumed peak loads should be of the order of magnitude expected for the monthly ratings; for example 110 per cent, 120 per cent, and 130 per cent may be assumed for the summer cycle if the ratings for these months are expected to be between these values. The curves of Figure 5, the transient-heating equation, the time-constant curve, and the various tables as explained in the appendix are of considerable assistance in making these computations. Monthly ratings are obtained from curves of peak hot-spot rise and peak oil rise plotted against per cent load for both the winter and summer cycles. The curves for the spring and fall months are obtained by assuming values halfway between the summer and winter curves. Various simplifications in the method of calculating become obvious as experience is obtained in making these computations. Hereafter these ratings which are used as a basis for normal everyday recurrent loading will be referred to as "recurrent" ratings.

These three methods of rating progressively applied result in considerably higher than name-plate ratings as is indicated by Table II, which gives the results for these three steps as well as the general method of the interim report[4] for a typical suburban distribution station. In this example the general method is the more conservative, but this is not always true.

Table II. Comparison of General and Individual Bases of Rating

Aliquippa Substation, Three-Phase, 3,000 Kva, 22.5/4.33 Kv, 400 Amperes
Location—Outdoors
Time Constant *T*—3.9 hours

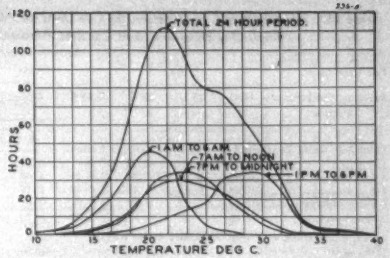
Method of Rating	Comparison of Rating (Per Cent) July	December
I. General (step 1—ambient-temperature basis)	100	123
II. Individual (step 2—test-data basis)	107	143
III. General (interim report, Figure 1)*	108	132
IV. Individual (step 3—load-cycle basis)	122	154
V. Individual (step 4—equal-life basis)	137	154**

* 70 per cent load factor in July and 64 per cent load factor in December.

** Limited by current-carrying parts.

Figure 3. July temperature-distribution curve for Pittsburgh and vicinity

The curves give the distribution for the total 24-hour period as well as for 6-hour periods



Industrial Versus Distribution Type of Substations

The same methods can be applied to rating both distribution and industrial substations. However, the monthly ratings have little meaning in industrial substations, as they usually have little or no seasonal trend, and in these cases the July rating would always be the limiting value. As the first step in rerating industrial substation transformers which have no seasonal trend, the load-factor method as given in the interim report which states "that the capacity may be increased 0.3 per cent for each one per cent the load factor is below 100 per cent" is quite satisfactory. However, it must be remembered that the magnitude of the hot-spot temperatures experienced at two stations having the same load factor but different load-cycle characteristics vary considerably. For example, a customer operating on one eight-hour shift may have the same load factor as one working three eight-hour shifts but would have considerably different hot-spot temperatures. More accurate methods for calculating the ratings are the individual methods discussed previously.

Increased Ratings Based on a Summation of the Life Consumed at Various Hot-Spot Temperatures (Fourth Step)

The fact that loads in most industrial plants show no seasonal trend suggests that one can afford to take more life out of the units during the summer months, as the insulation deterioration during the winter months may be almost negligible. This suggests a summation of the life consumed at each hot-spot temperature. This method of rating may be applied to either the distribution type or the industrial-type of station, but the resulting rating increases are much greater in the latter stations. This method which has been called the equal-life method is now in the development stage and has not been proved by field experience.

In this method of rating, one hour of operation at 95 degrees centigrade is defined as one life unit. Assuming that the rate of transformer insulation deterioration varies in accordance with the data given in reference 1, Figures 6 and 7, a curve of hot-spot temperature versus life units can be plotted as shown in Figure 1.

The method of rating can be explained by giving a typical example. Three typical ambient temperatures such as 35, 25, and 15 degrees centigrade are added to the 24-hour hot-spot temperature-rise cycle for three different peak loads such as 110, 125, and 140 per cent and set down in table form. The three temperature-rise cycles are obtained from the previous method of rating (step 3). The hot-spot temperatures are then converted to life units by using Figure 1. The transformer assumed was considered to have deteriorated to 50 per cent of its original insulation strength. When the life units for the periods and constant ambient temperatures assumed are averaged, they can be reconverted into an equivalent continuous hot-spot temperature. The summary of this work for Aliquippa substation is shown in Table III, and the curves of equivalent hot-spot temperatures versus ambient temperatures for the three loads are given in Figure 2. The per cent load figure used in this method refers to the highest peak occurring during a 24-hour period. The day is divided into four periods, because in this type of station the heavy load occurs during the high-ambient-temperature period and the light load during the low-temperature period. A similar group of curves should be obtained for the Decem-

Table III. Reduction in Life Measured in Life Units for Aliquippa Substation Temperature Cycle (for Three Assumed Constant Ambient Temperatures)

Per Cent Load	110			125			140		
Ambient Temperature Period	15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C
Total Life Units Consumed During One 24-Hour Period									
1–6 a.m.	0	0	0.06	0	0.01	0.11	0	0.05	0.30
7 a.m.–noon	0.05	0.25	1.30	0.21	1.06	4.52	1.30	5.29	17.27
1–6 p.m.	0.08	0.48	2.37	0.42	2.10	8.72	2.47	9.95	31.50
7 p.m.–12 midnight	0.02	0.14	0.78	0.09	0.57	2.74	0.44	2.20	8.77
24-hour period	0.15	0.87	4.51	0.72	3.74	16.12	4.21	17.49	57.84
Average Life Units Per Hour for Above Cycle									
1–6 a.m.	0	0	0.010	0	0.002	0.018	0	0.008	0.050
7 a.m.–noon	0.008	0.042	0.216	0.035	0.177	0.753	0.217	0.882	2.880
1–6 p.m.	0.013	0.080	0.395	0.070	0.350	1.460	0.418	1.660	5.250
7 p.m.–12 midnight	0.004	0.023	0.130	0.015	0.095	0.456	0.074	0.367	1.465
24-hour period	0.006	0.036	0.188	0.030	0.156	0.675	0.175	0.730	2.410
Equivalent Hot-Spot Temperatures* for Life Units in Above Table (Degrees Centigrade)									
1–6 a.m.	*t*<60	*t*<60	68	*t*<60	*t*<60	71	*t*<60	66	76
7 a.m.–noon	66	75	85	75	84	93	85	94	103
1–6 p.m.	69	79	89	78	88	98	89	99	108.5
7 p.m.–12 midnight	62	72	82	70	80	90	79	88	98
24-hour period	64	74	84	74	83	92	83	93	102

* Plotted in Figure 2.

ber temperature cycle if it differs to any great extent from the July cycle.

The next step is to obtain a curve showing the distribution of the outdoor ambient temperature versus hours for the months of July and December based on a number of years. Such curves for July based on the same four periods of the day are shown in Figure 3. A summation of the life units consumed during the month for the actual ambient temperatures and the three assumed peak loads can then be obtained by applying the July temperature-distribution values to Figure 2. This summation is given in Table IV. The summation of the life units divided by the number of hours in a month gives the average rate of consumption of life units and an equivalent hot-spot temperature for each per cent load.

A curve of per cent load versus equivalent monthly hot-spot temperature can then be plotted (Figure 4). Since the loads for the various days of the week usually vary, it is necessary to express the peak loads for each day in terms of name-plate rated current and convert to life units, make the summation, and reconvert to an equivalent monthly hot-spot temperature. This calculation is given in Table V. The limit for this method of rating is assumed to be the consumption of an average of 0.5 life units per hour which is equivalent to continuous operation at 90 degrees centigrade hot-spot temperature. The rate of deterioration is fairly high at this temperature, and so the limit may have to be reduced as experience in this method is obtained.

When the summer and winter load cycles differ, calculated values of equivalent monthly hot-spot temperatures for two months, July and December, usually suffice, as similar values for other months can be obtained by weighing the two calculated values, taking the accepted monthly ambient temperatures into consideration. From the monthly values the total life units expended annually and an equivalent annual hot-spot temperature can be obtained by the method given in Table V.

A word of caution should probably be added here. In order to take advantage of these increased ratings, it is essential that the transformer be in good condition, that is, the moisture content should be low, the current-carrying parts such as tap changers and bushings should have sufficient capacity, and the oil-expansion space should be ample. It is also necessary to check the oil temperatures to see that the rate of sludging is not too high.

Other Methods of Increasing Capacity

Rating transformers on an individual basis has an additional advantage in that it indicates what corrective measures are necessary to increase their capacity. For example, if oil temperature is the limiting factor, improved ventilation, the installation of additional radiators, or the installation of inert gas equipment which permits operation at higher oil temperatures will usually result in relatively large increases in capacity. If overexcitation is limiting the rating, installation of boosters in the neutral of star-connected transformers is the logical solution.

One result of the war has been the shift in the policy of rating two bank stations from the emergency rating of one transformer bank to the recurrent ratings of two banks. This has resulted in considerably increased station ratings, but it may necessitate load curtailment during some emergencies.

The rapid increase in the war industry and the difficulty in obtaining materials has necessitated the shifting of units from lightly loaded stations to release capacity for new war plants. Here again individually calculating bank capacities pay dividends, as banks having high time constants can be applied to the stations having peaked load cycles, and low time-constant banks can be applied to high load-factor stations where it is not possible to take advantage of the thermal capacity of the units. If the amount of inert gas equipment is limited, the ratings indicate the transformers on which this equipment can be used most profitably.

Auxiliary Cooling

When the other methods of increasing capacity have been exhausted, it is necessary to install some auxiliary method of cooling such as air blast, water-spray rings, or heat exchangers. The use of fans is usually the most convenient method, and, when sufficient fans are permanently installed, a 20 per cent increase in name-plate capacity is added to the recurrent rating without field tests. If more capacity is required, it is desirable to run tests on the units in the field. When tests are made, and the top-oil rise and gradients are established for the new conditions, the same three methods of rating as discussed previously can be applied. However, it must be remembered that the exponents used in this case will be 1.0 instead of 0.8. Additional capacity up to approximately 50 per cent is possible with this method of cooling.

Emergency Ratings

In spite of all precautions failures will occur. So emergency ratings still have an essential purpose in system operation, because they point out the bottlenecks in case of such failures. Wherever it is possible that emergency ratings may be exceeded, plans must be made to take care of the various contingencies that may arise.

In calculating emergency ratings, the usual method employed is that discussed under step 3; with higher temperature limits being assumed, 115 degrees centigrade is used for the hot-spot

limitations and 90 to 95 degrees centigrade for the top-oil limitation, the calculations being made for a typical 24-hour load cycle at the station considered. This calculated rating based on average conditions is used mainly for planning. Other short-time emergency ratings with higher temperature limits are used for special conditions where the load can be relieved by switching or by the installation of fans. When an actual emergency occurs, the load-carrying ability of the units is calculated on the spot, based on the actual ambients, loads, and probable duration of the emergency. It is desirable that all essential information on the transformer affected at the time of the emergency be available so that every possible kilovolt-ampere of capacity can be utilized without undue damage to the units. Curves or charts showing the variation of top-oil temperature and hot-spot gradients with load, together with the actual top-oil temperature and hot-spot readings, are very helpful in determining the allowable overload. In an actual emergency, every effort is made to relieve the overload by transferring load or by the use of fans, although the emergency ratings are not necessarily being exceeded, as it is desirable to prevent abnormal rates of insulation deterioration.

In the majority of cases, hot-spot meters are not installed, so in these cases

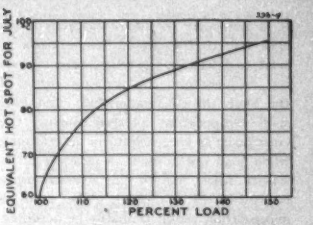


Figure 4. Illustrative curve for a distribution substation transformer showing the July equivalent hot-spot temperature versus per cent load

Table IV. Aliquippa Substation—Summation of Life Units for the Month of July

Ambient Temperature	Hours	110 Per Cent Load: Equivalent Hot-Spot Temperature (Degrees)	110 Per Cent Load: Life Units Per Hour	110 Per Cent Load: Total Life Units	125 Per Cent Load: Equivalent Hot-Spot Temperature (Degrees)	125 Per Cent Load: Life Units Per Hour	125 Per Cent Load: Total Life Units	140 Per Cent Load: Equivalent Hot-Spot Temperature (Degrees)	140 Per Cent Load: Life Units Per Hour	140 Per Cent Load: Total Life Units
1–6 A.M.										
10	1.18	<60			<60					
11.7	2.44	<60			<60					
13.5	4.88	<60			<60					
15.0	10.75	<60			<60					
16.7	20.00	<60			<60					
18.3	35.50	<60			<60					
20.0	45.75	<60			<60			60	0.0025	0.12
21.7	41.00	<60			<60			62	0.0036	0.15
23.3	17.00	<60			61.2	0.003	0.051	64	0.005	0.09
25.0	5.12	<60			62.5	0.004	0.020	66	0.0074	0.04
26.7	2.13	60.3	0.003	0.006	63.8	0.005	0.011	67.5	0.01	0.02
28.3	0.25	62.0	0.004	0.001	65.0	0.006	0.002	69.0	0.013	
	186.0			.007			0.084			0.42
7 A.M.–Noon										
11.7	0.38	63.0	0.004	0.002	71.0	0.019	0.007	81	0.115	0.04
13.3	1.80	64.5	0.006	0.011	72.5	0.024	0.043	83	0.165	0.30
15.0	3.31	66.0	0.007	0.023	74.0	0.032	0.106	85	0.225	0.75
16.7	6.25	67.7	0.010	0.063	75.6	0.046	0.288	86	0.260	1.63
18.3	13.50	69.3	0.014	0.189	77.3	0.074	1.000	88	0.360	4.86
20.0	24.00	71.0	0.019	0.457	79.0	0.090	2.160	90	0.480	11.52
21.7	29.54	72.5	0.025	0.738	80.7	0.110	3.250	92	0.66	19.50
23.3	29.00	74.0	0.032	0.928	82.3	0.145	3.820	93	0.76	22.00
25.0	26.54	75.5	0.044	1.170	84.0	0.200	5.308	95	1.00	26.54
26.7	22.35	77.1	0.058	1.300	85.2	0.230	5.140	96	1.15	25.70
28.3	15.48	78.7	0.078	1.210	86.8	0.300	4.644	97	1.30	20.10
30.0	8.60	80.4	0.110	0.946	88.3	0.380	3.270	98	1.50	12.92
31.7	2.87	81.9	0.135	0.388	90.0	0.490	1.407	100	1.95	5.60
33.3	0.88	83.4	0.170	0.150	91.5	0.600	0.527	101	2.25	1.98
35.0	0.75	85.0	0.225	0.169	93.0	0.760	0.570	103	2.90	2.18
36.7	0.75	86.8	0.280	0.210	94.7	0.980	0.735	104	3.30	2.48
	186.0			7.954			32.275			158.10
1–6 P.M.										
15	0.38	69.0	0.013	0.005	78.0	0.068	0.026	89	0.46	0.17
16.7	1.13	70.7	0.018	0.020	79.7	0.096	0.109	91	0.56	0.63
18.3	3.00	72.3	0.023	0.069	81.3	0.125	0.375	93	0.76	2.28
20.0	5.38	74.0	0.032	0.170	83.0	0.165	0.888	94	0.95	5.06
21.7	9.50	75.7	0.046	0.437	84.7	0.210	2.000	96	1.15	10.94
23.3	13.38	77.3	0.060	0.803	86.3	0.270	3.615	97	1.30	17.40
25.0	17.82	79.0	0.082	1.462	88.0	0.360	6.43	98	1.50	26.80
26.7	21.25	80.7	0.115	3.600	89.7	0.460	14.38	100	1.95	61.00
28.3	33.50	82.3	0.145	4.85	91.3	0.600	20.10	101	2.25	75.50
30.0	33.50	84.0	0.195	6.53	93.0	0.730	24.50	103	2.90	97.30
31.7	23.50	85.7	0.290	6.83	94.7	0.950	22.35	105	3.70	87.00
33.3	7.13	87.3	0.330	2.37	96.3	1.20	8.56	107	3.80	34.20
35.0	2.53	89.0	0.420	1.06	98.0	1.50	3.80	108.5	5.60	14.10
36.7	2.25	90.7	0.540	1.22	99.7	1.90	4.28	110	6.45	14.50
38.3	1.75	92.3	0.700	1.23	101.3	2.35	4.12	112	7.70	13.48
	186.00			30.66			178.67			460.35
7 P.M.–Midnight										
15.0	2.75	62.0	0.004	0.011	70.0	0.016	0.044	79	0.082	0.23
16.7	5.13	63.3	0.005	0.026	71.7	0.022	0.113	80	0.10	0.51
18.3	11.88	65.3	0.007	0.083	73.3	0.028	0.332	82	0.14	1.66
20.0	24.63	67.0	0.009	0.222	75.0	0.039	0.962	83	0.165	4.07
21.7	32.60	68.3	0.012	0.382	76.7	0.052	1.695	85	0.225	7.35
23.3	34.50	70.3	0.017	0.586	78.3	0.072	2.880	87	0.320	11.08
25.0	30.25	72.0	0.023	0.685	80.0	0.100	3.025	88	0.360	10.88
26.7	21.25	73.3	0.029	0.616	81.7	0.130	2.765	89	0.420	8.93
28.3	12.13	75.3	0.042	0.552	83.3	0.170	2.233	91	0.520	6.83
30.0	6.38	77.0	0.058	0.370	85.0	0.225	1.422	93	0.760	4.85
31.7	1.94	78.3	0.074	0.144	86.7	0.300	0.582	94	0.870	1.69
33.3	1.00	80.3	0.110	0.110	88.3	0.380	0.380	96	1.15	1.15
35.0	0.56	82.0	0.140	0.079	90.0	0.480	0.269	98	1.50	0.84
	186.00			3.87			16.700			60.07
Grand total	744.00	77.0	0.057	42.49	87.0	0.306	227.73	94.5	0.915	679.47

Table V. Aliquippa Substation Transformer Rating on an Equal-Life Basis for the Month of July

	Per Cent Load	Equivalent Hot-Spot Temperature	Life Units
5 weekday peaks*	137	91.5	0.61×120 hours = 73.20
Saturday peak	125	87.0	0.31×24 hours = 7.24
Sunday peak	100	60.0	0.0025×24 hours = 0.06
		90.0**	0.48×168 hours = 80.50

* All the weekday peak loads are the same magnitude and shape. The Sunday peak has a slightly different shape, but, because of its comparatively low magnitude, it has little effect on the results.

** The limit for this method of rating is assumed to be the utilization of an average of 0.5 life units per hour which is equivalent to continuous operation at 90 degrees centigrade hot-spot temperature.

it is necessary to add a calculated hot-spot rise to the top-oil temperature as read, to determine the transformer operating temperature. A running curve of the load, top-oil temperature, and hot-spot temperature plotted during the emergency is very helpful in determining when load curtailment is necessary. If service being fed by the stressed units is vital to the war effort, higher rates of depreciation would probably be accepted as long as a second failure is not imminent. Usually, however, when emergencies do occur, the ambient temperatures are lower, the loads are lighter, or the duration is shorter than the conditions assumed for calculating the ratings.

Conclusion

Individual transformer ratings for recurrent loads are amply justified by the additional capacity which is then known to be available for the war effort.

Some 20 customers have already been carried with loads up to 60 per cent above name-plate rating. AIEE limits of hot-spot operation have not been exceeded as yet.

So far there have been no failures of transformers due to loading nor any cases where it is believed that the rate of insulation deterioration is excessive.

Appendix

The following development is given to indicate a desirable form of the standard heating and cooling equations to use when a large number of calculations are to be made, using the step-by-step method of increasing ratings:

$$W = W_a + W_d$$

$$K\theta_u^{1.25} = C\rho\theta + K\theta^{1.25}$$

$$\rho\theta_i = \frac{K(\theta_u^{1.25} - \theta_i^{1.25})}{C}$$

Initial slope of temperature heating curve

$$= \rho\theta_i = \frac{\theta_u - \theta_i}{T}$$

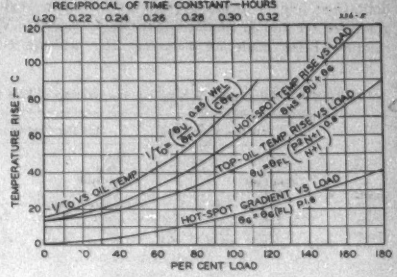
Therefore

$$\frac{1}{T} = \frac{K(\theta_u^{1.25} - \theta_i^{1.25})}{C(\theta_u - \theta_i)} = \frac{K\theta_u^{0.25}}{C} \frac{(1-R^{1.25})}{(1-R)}$$

$$\theta_u = \theta_{FL} \frac{(W_u)^{0.8}}{(W_{FL})^{0.8}} = \theta_{FL} \frac{(P^2N+1)^{0.8}}{(N+1)^{0.8}}$$

Figure 5. Illustrative curves for a typical transformer

These curves are used for rating transformers on an ultimate oil-temperature basis and for the thermal transient calculations



Therefore

$$\frac{1}{T} = \frac{K\theta_{FL}^{0.25}}{C} \frac{(\theta_{FL})}{(\theta_{FL})} \frac{(P^2N+1)^{0.2}}{(N+1)^{0.2}} \frac{(1-R^{1.25})}{(1-R)}$$

$$\frac{1}{T} = \frac{(W_{FL})}{(C\theta_{FL})} \frac{(P^2N+1)^{0.2}}{(N+1)^{0.2}} \frac{(1-R^{1.25})}{(1-R)}$$

(1) (2) (3)

$$\frac{1}{T} = \frac{1}{T_o} \frac{(1-R^{1.25})}{(1-R)}$$

(4)

1. The constant $(C\theta_{FL})/(W_{FL})$ is used as a time-constant reference figure for the transformers.

2. The term $(P^2N+1)/(N+1)$ for exponents of 0.2, 0.8, and 1.0 are set up in table form for values of N from 1 to 4 and P from 0.2 to 1.6 in 0.2 steps.

3. The term $(1-R^{1.25})/(1-R)$ can also be set up in curve or table form.

4. A curve of $1/T_o$ versus top-oil temperature is also plotted as shown in Figure 5.

5. A table of $(1-e^{-t/T})$ for various values of $-t/T$ is also of considerable assistance in solving the transient heating equation $(\theta_f - \theta_i) = (\theta_u - \theta_i)(1-e^{-t/T})$.

When one is solving the transient-heating equation for a 24-hour period, it is desirable to start the calculation at the end of the minimum load period. This is usually about six o'clock in the morning. The initial oil temperature (θ_i) which must be assumed for the first step, is usually about two or three degrees above the ultimate temperature rise for the minimum load. With a little experience, it is possible to estimate this temperature in advance within one degree centigrade. If the error in the original assumption is too great, the transient calculation should be continued until the maximum oil temperature is obtained. The values of (θ_u) and $(1/T_o)$ are obtained from Figure 5, the values of $(1/T)$ are obtained by multiplying $(1/T_o)$ by the function of R as explained above. The values of $(1/T_o)$ for the heating portion of the cycle corresponds to (θ_u) and for the cooling portion of the cycle to (θ_i).

List of Symbols

C = thermal capacity
N = ratio of copper to no-load loss
P = ratio of load amperes to name-plate rated amperes
$p = d/dt$
R = ratio of (θ_u/θ_i) for cooling cycle and (θ_i/θ_u) for heating cycle
t = time in hours
T = time constant
T_o = time constant for zero initial rise
W = watts loss in transformer
W_d = watts dissipation
W_s = watts stored
W_{FL} = watts loss at full load under operation conditions
W_u = watts loss at load which would produce θ_u
θ_{FL} = oil-temperature rise at full load under operating conditions
θ_i = initial oil-temperature rise
θ_u = ultimate oil-temperature rise
θ_f = final oil-temperature rise
θ_G = temperature gradient between hot-spot and top-oil temperature (ultimate values are used throughout)
θ_{HS} = hot-spot-temperature rise

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2. American Standard C-57. Page 87, section *f*.

3. Emergency Overloading of Air-Cooled Oil-Immersed Power Transformers by Hot-Spot Temperatures, V. M. Montsinger, P. M. Ketchum. AIEE Transactions, volume 61, 1942, pages 906–16.

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Protective Relaying for Long Transmission Lines

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UP to a certain length of transmission line, conventional distance relays will readily distinguish internal faults, for which the line should be opened, and external faults, load conditions, and power swings, for which the line should not be opened. This distinction is based on the magnitude of the impedance or reactance of the line as it appears to the relay. This impedance will be referred to hereafter as the input impedance and is determined by the current and voltage existing at the relay location.

The magnitude of the input impedance will distinguish clearly between internal and external faults for any length of lines, but, as longer lines are considered, the difference in impedance between load and fault conditions becomes less and may even be reversed. On the Kansas–Nebraska line, using conventional distance relays, there would be undesirable tripping on power swings from which the system can recover easily, such as those that may occur when the line is reclosed instantaneously after clearing a temporary fault. The power swing in this case is caused by the two terminals having drifted apart slightly during the reclosing period, because the sending end has lost load, causing it to speed up, and the receiving end has lost power, causing it to slow down; therefore, when reclosure occurs, a large amount of power flows and tends to draw the two ends together and thereby reduces the flow of power, and an oscillation is started.

Although there is little difference in the impedance magnitude during fault and load conditions on very long lines, there is, fortunately, a considerable difference in phase angle. During load conditions the heavy charging-current component tends to make the input impedance have a leading power-factor, whereas during an internal fault much of the line capacitance is short-circuited and the input impedance is therefore lagging considerably as shown in Figure 4 on curve Z_B.

As a result of the foregoing, impedance magnitude was once more used to distinguish between internal and external faults, but the distinction between faults and load conditions was based on phase angle, a quantity which was so selective that it was possible to differentiate further between load conditions, so that tripping was prevented on normal loads and power swings but allowed on out-of-step conditions.

No special relay construction was used. All the relay elements were of standard design with the reactance and resistance of their potential coil circuits arranged to obtain the desired characteristics. The equipment has certain advantages over the conventional distance-carrier-relay equipment and is not limited to extremely long lines; it can be used also for lines as short as about 50 miles. The equipment was developed for the 270-mile 154-kv interconnection between Nebraska Power Company and Kansas Gas and Electric Company systems to meet the general performance specifications laid down in a companion paper,[1] and it has been applied since to the "Ark–La" 154-kv line, approximately 200 miles long in Oklahoma and Arkansas.

Impedance Diagrams

If capacitance and shunt loads are neglected, the transmission of power over a simple single-line system can be represented vectorially as shown in Figure 2 wherein V_r and V_r represent the voltages behind the terminal generator impedances, and the voltages V_a, V_b, and so forth, are the voltages existing at various intermediate points. The system interchange current I_s and the angle δ will both increase in magnitude as the power transmitted is increased.

The relays located at the various intermediate substations will see impedance values determined by the relation between the substation voltage (such as V_a or V_b) and the current I_s. This value is the equivalent input impedance of the system and will be referred to as the input impedance. As the load changes, θ, V_a, V_b, I_s, and the input impedance will change. In a companion paper[1] the loci of the input impedance at a given location for various ratios of line-terminal voltages are shown to be circles on a resistance-reactance diagram. Furthermore, it is shown that, for the special ratio of line-terminal voltages $E_s/E_r = D$, where D is one of the "general line constants," the radius of such a circle is infinity, and the circle becomes a straight line.

For short lines where capacitance and shunt loads can be neglected the general line constant $D=1$, and thus, if the terminal voltages V_r and V_s are always equal, the loci of input impedance as "seen" from terminals R and S (Figure 2) are straight lines coinciding with the 0 per cent and 100 per cent lines of the distance scale on Figure 3. When these straight-line loci obtain simultaneously at the two terminals of a circuit, the loci of the impedances "seen" at intermediate points on the circuit are likewise straight lines and form a family of parallel lines as in Figure 3, which was first presented to the Institute in a discussion by J. H. Neher.[2]

Under the conditions for which it is valid, that is, systems with negligible capacitance, no shunt load, and equal terminal voltages, Figure 3 shows that the input impedance, as seen from any particular point, is a minimum when the

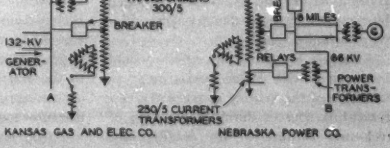

Figure 1. Connections of relays relative to transmission line

Paper 43-38, recommended by the AIEE committees on power transmission and distribution and protective devices for presentation at the AIEE national technical meeting, New York, N. Y., January 25–29, 1943. Manuscript submitted November 20, 1942; made available for printing December 23, 1942.

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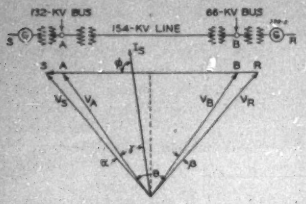


terminal voltages are displaced 180 degrees, and is infinite when the equal terminal voltages are in phase, since under this condition there is no current flow.

This type of chart is very convenient for determining whether or not a particular relay will operate for a particular amount of load transfer or for a particular angular displacement under swing conditions. To determine this, it is necessary only to plot the relay pickup characteristics on the diagram (being sure to plot both characteristics to the same scale) and observe at what value of the line-displacement angle θ the relay characteristic crosses the line characteristics.

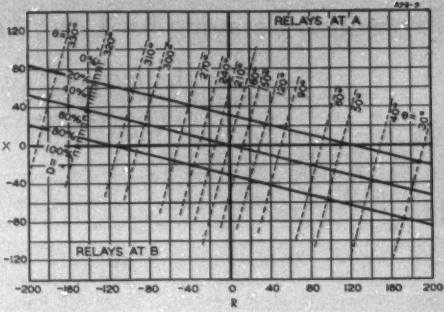
In the more general case for which Figure 3 is not valid (that is, where terminal voltages are not equal, line capacitance is large, or there are important shunt loads), it is evident that the families of input-impedance circles applying to each relay location must be examined and compared with the relay pickup characteristics to determine if that relay is suitable for the proposed application.

In Figure 4, which represents a typical input-impedance circle for the 270-mile Kansas–Nebraska interconnection point A represents the system impedance for a fault at the far end of the line, and point D the impedance for a more remote fault up to which backup protection is desired. The third zone of the conventional impedance relay set to operate in backup time up to D would also operate on the maximum load of 50,000 kw. The conventional reactance relay with the same setting would not operate on this load, because it is outside the characteristic of the starting unit, but it could not be used as a basis for carrier relaying, because the impedance fault detector would experience the same trouble as the third step of the impedance relay and would transmit carrier and set up the out-of-step blocking circuit, and thereby delay tripping on faults.

A further margin of impedance would be required with either kind of relay to take care of the drifting apart of the two generating sources during the period of reclosure, because of the leading and losing load end speeding up and the lagging end losing generation and slowing down; otherwise, the relays would trip on the reduced impedance condition caused by the two stations swinging apart before reclosure.

Figure 2 (left). Vector diagram of circuit in Figure 3

Figure 3 (right). Input-impedance diagram for relays at various locations along a line with $X/R = \tan 75°$ connecting two systems or machines, applicable to the special case in which $V_s = V_r$, assuming no shunt load and neglecting shunt capacitance



D = Distance of relay location from equivalent internal voltage of the leading end V_s, in per cent of total impedance from S to R

The co-ordinates are scaled in per cent of total impedance from S to R. Abscissas are resistance; ordinates are reactance

The problem then was to design relays which would:

1. Trip instantaneously for faults up to A, including arc resistance.
2. Trip on out-of-step conditions and swings from which the system will not recover.
3. Not trip on loads up to the steady-state power limit.
4. Trip in delayed time up to D, for backup protection.
5. Not trip on swings from which the system would be likely to recover, that is, roughly up to $\delta = 110$ degrees.
6. Provide carrier blocking for external faults.

The Solution

Items 1, 2, and 3 require that the relays should trip instantaneously for conditions within the area A-A' 120 degrees–B-B' 240 degrees. A circle fits very well around these points (see Figure 4), the center of the circle being on the line-impedance line AB, about 60 degrees lagging the R axis, though it also includes some loads which should be excluded under item 3. Such a circle is the characteristic of a directional relay with a voltage restraint, which is similar to the starting unit of the standard reactance-type distance relay. This unit measures a quantity of the form $I \cdot f(\phi)/V = Y \cdot f(\phi)$ which is "admittance at an angle." Since this quantity is in mhos, the unit is called a "mho unit," corresponding to the term "ohm unit" applied to the reactance-measuring unit of the distance relay, which measures "impedance at an angle."

Items 4, 5, and 6 require a relay combination which will operate within the shaded area of Figure 5. The straight sides of the area are similar to the characteristics of a reactance unit except that they represent constant impedance at 20 and 30 degrees leading the unity-power-factor position instead of lagging it by 90 degrees. The ends of the area were cut off by the circular characteristic of an impedance unit as shown in Figure 5. In other words, by connecting a contacts of the impedance unit and the two ohm units in series with a timing unit, backup protection with delayed tripping occurs in the lightly shaded area KPQ. By connecting a set of b contacts of the three units in parallel in the carrier-control circuit, carrier blocking is provided over the same area KPQ, which disposes of items 4 and 6.

In reference to items 2 and 5, by connecting the contacts of the ohm units in series with those of the mho unit, the value of δ at which tripping occurs can be controlled accurately by the settings of the ohm units; otherwise, this limit is determined by the mho unit, whose setting is based on the length of the line and hence cannot be adjusted to a value of δ also. With the present line, Figure 5 shows that the mho unit would prevent tripping on swings up to about $\delta = 75$ degrees, but it was decided that about 100 degrees would be required to provide sufficient margin for power swings, especially after instantaneous reclosure of the breakers following a fault.

Relay Settings

At this point it will be apparent why 20- and 30-degree characteristics were

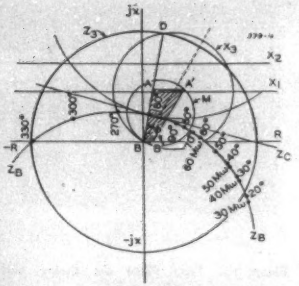


Figure 4. Impedance diagram of load and fault conditions on long line at terminal *B* of Figure 1

Angles marked on Z_B circle are angles between terminal voltages

AB = impedance of line to three-phase fault at end of line = 370 ohms

AA' = arc resistance with single-end feed, 60 miles per hour wind and minimum generation—fault at *A*—125 ohms

BB' = ditto with fault at *B*, near bus—32 ohms

AD = reach of backup (zone 3) protection

Mw = megawatts sent from *A* to *B*

chosen for the ohm units. As the characteristics were pulled in closer to the origin in order to prevent tripping on swings up to $\delta = 110$ degrees, they had to be made parallel to the boundaries of the tripping area in order to insure tripping for all fault conditions.

The 20-degree characteristic can be as close to the line-impedance vector as desired but, the closer it is, the lower the ohmic pickup, and hence the higher the potential burden. A pickup of 42 ohms was chosen first for this unit but was increased later to provide higher relay torques.

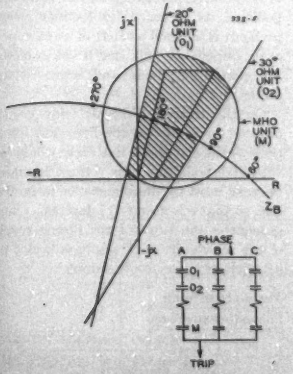
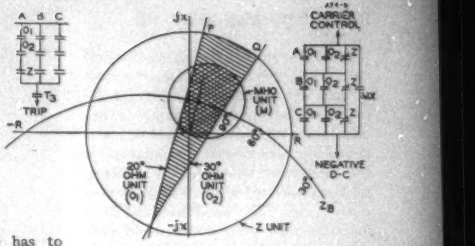


Figure 5. Tripping characteristic on phase faults and out-of-step conditions

Figure 6. Blocking and backup protection on phase faults and power swings

Carrier blocking and time backup are provided in the shaded areas. Carrier is shut off by the mho unit in the double shaded area allowing instantaneous tripping for internal faults



The 30-degree characteristic has to allow for the maximum arc voltage, which will be during minimum generation and single-end feed.

Some approximate calculations of arc resistance for this circuit indicated that it might be between 50 and 70 ohms for a nearby fault and between 100 and 150 ohms for a fault at the far end. To allow for these arc values and to prevent tripping on swings required a setting of 72 ohms.

The diameter of the mho-unit circle represents its setting in ohms. To cover the fault area *AA' BB'* it was made initially about 375 ohms but was increased later to provide greater pickup torque and consequently faster action on far-end faults. The setting of the impedance unit was merely a rough margin between nearby and remote faults, so as to prevent the carrier and the timing unit from being operated unnecessarily; the value chosen was 500 ohms.

The effect of combining these circuits and their characteristics is shown in Figure 8, and explained in the next few paragraphs.

Over-All Operation of Protective Relays

Figure 8 shows the various zones of operation, and Figure 9 is a schematic diagram of the d-c connections.

A phase fault on the 154-kv line is within both the carrier and tripping zones (see Figure 8 zone T_1). The ohm units O_1 and O_2 and the Z unit in the same phase open their *b* contacts in the carrier-control circuit, turning on carrier. The mho units *M* pick up the *MX* auxiliary relay which by-passes the contacts of the *O* and *Z* units and restores negative direct current to the grid of the oscillator tube in the transmitter stopping carrier. Another contact of the *MX* relay de-energizes the receiver-relay holding coil, and, with carrier off, the receiver relay then closes its contacts and causes tripping in a total time of about $1\frac{1}{2}$ cycles.

A ground fault picks up the over-current fault detector *G* whose *b* contact removes negative direct current from the transmitter grid while the current polarized directional relay *GD* reapplies negative direct current and stops the carrier. Other contacts of *GD* de-energize the receiver-relay holding coil and complete the tripping circuit through the contacts of the receiver relay.

An external fault within the range of the mho unit will not trip instantaneously through the receiver relay, because, at the faulted end, the mho unit is reversed and hence does not shut off carrier, so that instantaneous tripping is prevented, but the relay will trip in intermediate time (T_2), if the fault is not cleared by the correct breaker.

An external phase fault within the range of the ohm and impedance units turns on carrier as before and starts the timing unit (see zone T_3C of Figure 8), but at the faulted end the mho unit is reversed and hence does not shut off carrier, so that instantaneous tripping is prevented, but backup time (T_3) tripping will occur if the correct breaker does not trip. If the carrier is off for maintenance, the receiver-relay contacts *R* are short-circuited by the switch *SC*, so that tripping occurs directly when the mho unit closes (zones T_1 and T_2). Instantaneous tripping with "carrier off" is limited to the line and a little beyond the windings of the transformers at the far end by the setting of the mho units. If the fault is beyond this zone, the mho unit does not operate, and the timing unit operates in backup time (T_3), if the fault has not already been cleared. A fault within the reach of the mho unit but beyond the location of the opposite mho units will be cleared in intermediate time (T_2) if not cleared already by carrier relays.

An external ground fault within the range of the overcurrent blocking unit (G_1) turns on carrier, but at one end the directional unit (*GD*) is reversed and does not turn off carrier, so that instantaneous tripping is prevented. In that case, the time overcurrent ground relay (type *IAC*) provides backup protection, unless the proper differential relay has already operated.

Receiver Blocking Relay, RB

Carrier is started for all fault conditions, though it may be stopped almost at once by the directional relay, if the fault is in the tripping direction. If tripping occurs, the carrier will not be maintained for more than the time taken for the directional relay and its auxiliary relay to operate, which will be one to three cycles. The persistence of carrier for more than three cycles would indicate an external fault and would operate the *RB* relay which is arranged to pick up in three to four cycles and drop out in six cycles.

The *RB* relay energizes the holding coil of the receiver relay, so that, during external faults, the *RB* relay maintains the blocking action for another six cycles after the carrier has been shut off by the resetting of the relays after the fault has been cleared. * This arrangement prevents tripping through the carrier relays unless the condition is maintained, as would be the case if a second fault occurred just after the first one had been cleared.

Tripping on Out-of-Step Conditions

The conventional relay equipment for short lines employs blocking relays which prevent tripping on both power swing and out-of-step conditions. These conditions are recognized by means of an impedance unit which applies blocking after a time delay of about 0.1 second, unless it is prevented by an instantaneous impedance unit with a lower ohmic setting; in other words, a swing is distinguished from a fault by the rate of change of impedance. To effect tripping during actual out-of-step conditions requires a somewhat expensive relay which requires several power oscillations before it can be sure of the out-of-step condition.

With the present equipment not only are the foregoing features inherent in the relay characteristics, but they trip instantly when the angle crosses a threshold value. Not only is no time required for the decision, but the angle itself can be set accurately from system impedance curves. In the present case a setting of 72 ohms prevents tripping for power swings up to $\delta = 110$ degrees.

The Mho Unit

The mho unit is a four-pole induction-cylinder unit, see Figure 7a; the two long poles have a potential winding whose flux induces eddy currents in the induction

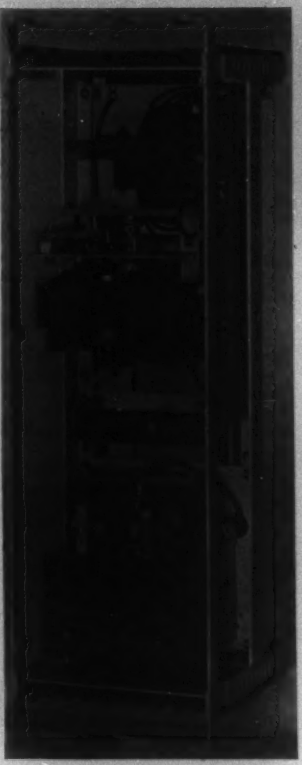


Figure 7a. Type CGZ special distance relay

The upper is the mho unit
The lower is the *Z* unit

cylinder or rotor which react with the fluxes from the two short poles to produce torque. One of the short poles has two current windings excited by the currents in two of the phases, so as to make a flux proportional to their delta sum. The other short pole has a potential winding excited by the potential between the same two phases. The polarizing potential winding has voltage from the next lagging pair of phases. As an example, phase 1–2 relay has a torque proportional to: $V_{23}[(I_1 - I_2)\cos(\sigma - \phi - 30 \text{ degrees}) - V_{12}\sin\sigma]$, where σ is the angle between V_{12} and V_{23}, so that it operates when $(I_1 - I_2)\cos(\beta - \phi - 30 \text{ degrees}) > V_{12}\sin\sigma$, or when the admittance of the circuit

$$\frac{(I_1 - I_2)\cos(\sigma - \phi - 30 \text{ degrees})}{V_{12}\sin\sigma} > Y \text{ mhos.}$$

The value of Y is adjusted by an auxiliary potential transformer with nine

Figure 7b. Type *PDM* d-c timing unit (T_2 and T_3)

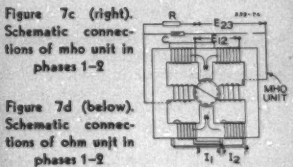


Figure 7c (right). Schematic connections of mho unit in phases 1–2

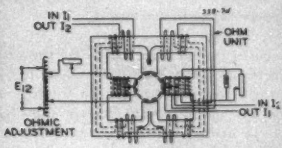


Figure 7d (below). Schematic connections of ohm unit in phases 1–2

ten per cent and ten one per cent taps, so that one per cent steps can be obtained.

Apart from its suitability for this application, the mho unit has the great advantage over the ohm unit of the conventional distance relay of not requiring a directional unit, since it is itself directional. On long lines, where arc resistance is not a large percentage of the total impedance, its accuracy for distance measurement is as good as that of a reactance or an impedance unit, and it is less likely to operate on loads and swings than either unit.

On the Kansas–Nebraska line $\phi = 72$ degrees for faults on the line, and for a fault at the end of the line there would be very little collapse of the voltage triangle, because most of the impedance is in the line, so that σ is about 115 degrees. Consequently, the ratio of the ohmic reach of the mho unit on three-phase faults to its reach on phase-to-phase faults is

$$\frac{\text{Three-phase-reach}}{\text{Phase-to-phase reach}} = \frac{\sin 120° \cos(115° - 72° - 30°)}{\sin 115° \cos(120° - 72° - 30°)}$$

$$= \frac{0.866 \times 0.974}{0.906 \times 0.951} = 0.98$$

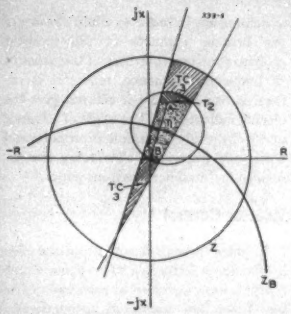


Figure 8. Over-all relay characteristics

In other words, the reach on three-phase faults is approximately the same as on phase-to-phase faults.

In order to provide fast operation on three-phase faults close to the station, the polarizing potential coil of the mho unit is made resonant, so that, when the line potential is suddenly reduced to substantially zero by the fault, the potential across the relay winding is maintained long enough to insure reliable operation. The connections of this circuit are shown in Figure 7c and are the same as are used in the standard *GCX* distance relay.

The Impedance Unit

The impedance unit is of the eight-pole induction-cylinder design (see Figure 7a), three of the poles producing current-operating torque and three producing potential restraining torque.

The windings on the three current poles are in series, but the middle pole has a copper sleeve, so that its flux is out of phase with that of the other two poles and hence produces torque. A similar method is used in the potential circuit where the middle pole is dephased by a series resistor. In the appendix, it is shown that this arrangement produces a steady torque, irrespective of the angle between the pole fluxes.

The induction-cylinder construction not only provides a high-torque low-inertia device, but it also has a pickup and dropout which are very close together; this is advantageous in a fault detector for very long lines where there is little distinction between the system impedance during load, swing, and fault conditions.

Its operating torque is proportional to the current squared, and its restraining torque is proportional to the adjacent voltage squared, so that the relay operates when the system impedance falls below its calibration. The pickup is independent of phase angle within four per cent, because of the steady torque of the induction cylinder.

Since the relay has only one current circuit, the reach on three-phase faults is 15 per cent more than on phase-to-phase faults, but this is of no consequence, because this unit controls the operation of carrier and time backup protection and hence need not be accurate.

The Ohm Unit

The ohm units are the same as that of the standard reactance-type distance relay, see Figure 7a, except that one is arranged to measure the 20-degree and the other the 30-degree component of impedance, instead of both measuring the reactive component. The change from the standard ohm unit was accomplished simply by changing the constants of the potential circuit to obtain the desired phase angle.

Each unit has four double-current windings arranged as in Figure 7d, so as to create a magnetic flux between the front and back poles of the unit. The left-hand pole has a potential winding whose phase angle is adjustable by a series resistor between 70 degrees and 55 degrees, so that the relay characteristic can be adjusted for maximum torque between 20 and 35 degrees. The right-hand pole has another double-current winding which is shifted 90 degrees in phase from the first by a floating secondary winding having a parallel capacitor and resistor.

The current flux from the front and back poles reacts with the flux from the right-hand pole to create an operating torque $K(I_1-I_2)^2$ where I_1 and I_2 are the currents in the double-current windings of the relay associated with phases 1 and 2. It also reacts with the flux from the potential pole to produce a restraining torque $E_R(I_1-I_2)\cos(\phi-\Delta)$ where Δ is the angle for maximum EI torque.

At the balance point the two torques will be equal so that $E_{12}\cos(\phi-\Delta)=K(I_1-I_2)$, but $E_{12}=E_1-E_2=(I_1-I_2)Z$, where Z is the impedance of a line conductor between the relay and the fault, therefore, $Z_1\cos(\phi-\Delta)=K$. K is adjustable by means of a transformer with one per cent taps.

The two ohm units in each phase have their contacts in series and are polarized in opposite directions (the 20-degree unit operates on incoming K_W and the 30-degree unit on outgoing K_W) so that the system impedance has to be between their characteristics in order to turn on carrier or to trip (see Figure 6).

Timing Unit

The timing unit is controlled by the same relays that control the carrier and is of the same design as used in the standard distance relay. It provides a short time delay for faults in the protected zone in case the carrier tripping is inoperative and a longer time delay for faults in the low-voltage windings of the transformer, and, during minimum generation at the other station, the third zone may reach a short distance into the system beyond the power transformer at the other station.

The speed of the timing unit is controlled by a centrifugal friction governor (see Figure 7b). A d-c solenoid winds up the spring which operates this unit. Two adjustable insulated contact arms close the intermediate and backup time contacts. The timing scale is graduated in tenths of a second up to three seconds. A time setting is made easily by loosening a knurled nut on the main shaft and setting the contact arms.

Ground Relays

The relays and connections for ground faults is the same as in the standard carrier-pilot relay scheme, except that the overcurrent tripping relay was made

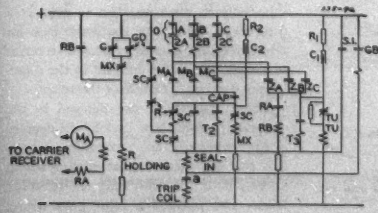


Figure 9. Circuits of carrier relays for long transmission lines

Figure 9a (left). D-c and tripping circuits

SC switch contacts shown in position for carrier on

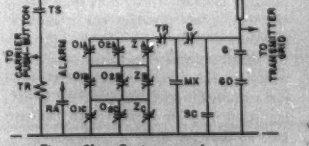


Figure 9b. Carrier control circuits

directional, thus eliminating an extra directional relay. The blocking unit is a plunger overcurrent unit which operates in a fraction of a cycle to remove negative bias from the grid of the oscillator tube in the carrier transmitter (see Figure 9b) and thus starts carrier. The tripping unit is an eight-pole induction-cylinder unit with alternate poles provided with a copper sleeve to lag their flux, so that a torque can be produced. An induction unit is used for the tripping function, because it is least liable to trip undesirably on transient conditions.

Transformer Differential Relays

These are the standard high-speed type *HDD* relays with harmonic restraint which were described in a previous paper.[3] Because of the absence of breakers on the line side of the transformers, it was necessary to provide a means of tripping the breaker at the other end for a transformer fault. This was done by arranging the differential relays to close a three-phase grounding switch on the 154-kv line which creates a fault and causes tripping at the other end.

Reclosing Relays

After the breakers at each end of the line have been tripped, they can be reclosed in four different ways:

1. Manually using the synchroscope.
2. Manually by automatic synchronizing.
3. Automatically with instantaneous or delayed reclosing.
4. Automatically with automatic synchronizing.

Figure 10 shows a detail of the reclosing circuit. Manual closing is done by closing the manual control switch (*CSW*) and the synchronizing switch on the right of Figure 10. Automatic synchronizing is initiated by turning switch 43 to position *S;* then the contacts 25 of the automatic synchronizing relay (type *GES*) will energize the reclosing circuit, provided that the voltage check relay 83 has operated, closing contacts 83*X* of its auxiliary relay.

In normal automatic operation it is customary to set the switch 43 at the position marked *R* and *S* at each end of the line. This provides one immediate reclosure at both ends of the line through the instantaneous step of the type *AC*-1 reclosing relay; this reclosure is made as fast as possible by connecting the initiating relay 79*X* in parallel with the trip coil, so that the timer is started at once, and the closing coil will be energized as

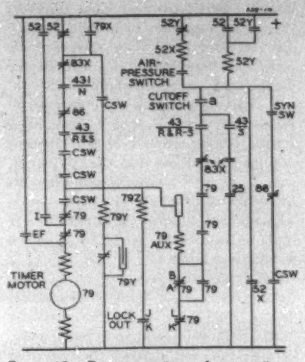


Figure 10. D-c connections of automatic reclosing circuit

soon as the breaker *b* switch is closed. If the fault persists and one end recloses first and energizes the line, the voltage-checking relay 83 at the other end operates; this opens contact 7–8 of 83*X* and transfers the control to the automatic synchronizing relay 25. Similarly, if only one end trips, the other end can only reclose through the synchronizing relay 25.

A number of combinations are possible: for instance, one end may have the selector-switch 43 set to *R* and the other to *S*, so that one end recloses at once and the other through the synchronizer, and, of course, the two may be interchanged. If both ends are at *R* and have similar *AC*-1 time settings, immediate reclosure will occur at both ends three times unless the breaker stays in after the first or second reclosure; with different timer settings only the early end will reclose immediately. Other combinations are *R* with *R* and *S*, *S* with *R* and *S*, and *S* with *S*. Three reclosures are provided by the type *AC*-1 reclosing relay at adjustable intervals, the maximum setting being three seconds; after the third reclosure the reclosing circuit is locked out.

The type *GES* automatic synchronizing relay 25 gives the closing indication to the circuit breaker slightly in advance of

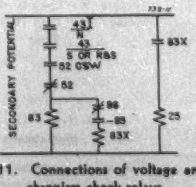


Figure 11. Connections of voltage and synchronism check relays

synchronism, in order to effect closure of the breaker contacts at the moment of synchronism, regardless of the amount of frequency difference, unless it is excessive, in which case it will not give the closing indication. The angle of advance at which the relay functions is proportional to the slip frequency. The relay was described in detail in a previous paper.[4]

Reactor Control

In order to control voltage on the 154-kv line three 5,000-kva three-phase shunt reactors were provided at each end of the line which are connected automatically to the power transformer tertiary winding whenever overvoltage occurs or when the terminal breaker is opened. A short time delay is provided to avoid switching in the reactors during transient voltage disturbances resulting from line switching or from faults on the line.

Phase Faults During Heavy Load Conditions

Before the relay equipment was shipped, it was tested thoroughly on an artificial transmission line in the factory. These tests revealed that the directional properties of the mho units could not be relied upon above a certain value of load, that is, above a certain value of θ, the angle between the electromotive forces at the two ends of the line. This is caused by the fact that the voltage at the far end of the line controls the phase angle of the fault current, while the phase angle of the relay characteristic is controlled by the voltage at the near end. The fault current may therefore be far from the maximum torque angle of the relay and can be shifted still farther by the collapse of the voltage triangle on a nearby fault until it is near the zero torque position. Finally the superposition of the load or swing current actually may cause reverse torque, so that the mho unit may trip for a fault on the other side of the local transformer.

The likelihood of wrong tripping increases with the angle θ between the voltages at the ends of the system. With a bus fault the restraining torque of the mho unit is zero, so that it acts as a directional relay, and the conditions for wrong tripping can be expressed in terms of the components of current in the direction of maximum torque of the relay.

These expressions are derived in the appendix; they show that $\theta = 48$ degrees is approximately the maximum separation that can exist without causing wrong operation of the mho unit on incoming load. The phase 1–2 relay goes wrong

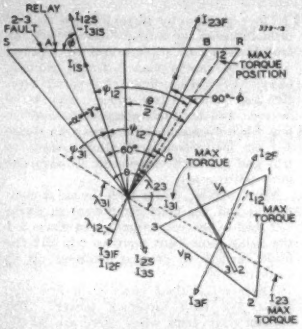


Figure 12. Vector diagram of bus fault with outgoing power

for a phase 2–3 fault; the other relays require more separation to make them go wrong.

Since power transfers in excess of this are expected, it was necessary to seek a solution. The solution to this difficulty was the addition of a polyphase directional-relay type *CAP*15*A* with its contacts arranged to supervise those of the mho unit. This relay has a torque proportional to the arithmetical sum of the 70-degree lagging components of the positive-sequence and negative-sequence volt-amperes and was described in a previous paper.[6]

The *CAP* relay operates correctly under these conditions of a bus fault for load conditions causing up to $\theta = 85$ degrees. The maximum loads expected would give $\theta = 53$ degrees, so that an adequate margin is provided. Under power-swing conditions it is, of course, possible to have more than 85 degrees displacement, but such a separation could only be reached during the reclosing period and would require a permanent fault; otherwise the tripping condition could not occur. While it was found possible to take care even of this condition, by means of a negative-sequence directional relay with a closing mechanical bias to permit operation on three-phase faults, yet it was regarded as a very improbable coincidence, and it was decided that even the *CAP* relay might never be called upon to prevent wrong operation.

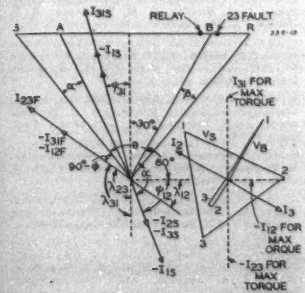


Figure 13. Vector diagram of bus fault with incoming power

System Tests

The calculated settings of the relays were checked very closely by their behavior during the system tests which are described in a companion paper. Internal and external faults were applied with zero power exchange and with the interconnection loaded approximately to its stability limit, all relay operations were correct.

Conclusions

The magnitude of the input impedance of a transmission line is always a reliable basis for locating faults, but, as the length of the line increases, impedance magnitude becomes less reliable for distinguishing between load and fault conditions. Fortunately, however, there is at the same time an increasing difference in phase angle.

Distinction by angle has the advantage that the degree of system separation for tripping can be controlled accurately and can be effected without delay.

Symbols

V_s = generator electromotive force at sending end

V_r = generator electromotive force at receiving end

V_a, V_b = terminal voltages at A and B

A, B = relay locations on transmission line

δ = angle between terminal voltages V_a and V_b

θ = angle between generator electromotive forces, V_s and V_r

α = angle between V_r and V_a

β = angle between V_r and V_b

σ = angle between polarizing and restraining potentials on the mho unit

ψ = angle between V_a or V_b and load component of current

λ = angle between V_a or V_b and fault component of current

ϕ = power-factor angle of input impedance looking into line $= \tan^{-1}\frac{X}{R}$

The following symbols are used on the diagrams:

M—Mho unit (phase directional unit)

O—Ohm unit

Figure 14. Relay panel

Z—Impedance unit

R—Receiver relay

TU—Timing unit

MX—Mho-unit auxiliary relay

RA—Receiver auxiliary relay

RB—Out-of-step blocking relay

G—Ground-fault detector

GD—Ground directional relay

GB—Ground backup relays

SI—Seal-in relay

TR—Carrier-test relay

TS—Carrier-test switch

SC—Carrier on-off switch

T—Target

A, *B*, *C* refer to the phases, for example, Z_A, Z_B, Z_C

1, 2, 3 refer to the zone of time or impedance, for example, O_1, O_2, O_3, T_1, T_2, T_3

25—Synchronizing relay

43—Transfer switch

43*I*—Inspection transfer switch

52—Circuit breaker

79—Reclosing relay

83—Voltage checking relay

86—Lockout relay.
X, *Y*, *Z*—Auxiliary relays, such as 83*X* or 79*Y*

Appendix

The mho unit has zero voltage restraint during a bus fault involving more than one phase and therefore acts as a directional relay under that condition. The torque due to the swing current is $I_S \cos \psi$ where ψ is the angle measured from I_S to the maximum torque position. The torque due to the fault current is $I_F \cos \lambda$ where λ is the angle measured from I_F to the maximum torque position.

The following is an approximate analysis intended more as an explanation than as a rigid proof. The rigid analysis is extremely long and involved.

Referring to Figure 2, and assuming $V_S = V_R = V$ and that a 2–3 fault causes no drop in V_1

$$V_A \cos\left(\frac{\theta}{2}-\alpha\right) = V\cos\frac{\theta}{2} = V_B\cos\left(\frac{\theta}{2}-\beta\right)$$

Then, using values of Z_A taken from the system impedance circle for $V_S = V_R$, $I_{1S} =$

$$\frac{V\cos\frac{\theta}{2}}{Z_A\cos(\theta-\alpha)}$$

at the end with outgoing power or

$$\frac{V\cos\frac{\theta}{2}}{Z_B\cos\left(\frac{\theta}{2}-\beta\right)}$$

at the end with incoming power. Referring to Figure 12, with outgoing power

$$I_{12S} = -I_{31S} = \frac{3}{2}I_{1S} = \frac{3}{2}\,\frac{V\cos\frac{\theta}{2}}{Z\cos\left(\frac{\theta}{2}-\beta\right)}$$

The fault current is $\sqrt{3}V_S/2Z_{SB}$ from the sending end to a relay at B, and it is $\sqrt{3}V_R/2Z_{RA}$ from the receiving end to a relay at A. The total relay torque is $V_{pol}(I_S\cos\psi + I_F\cos\lambda)$ where V_{pol} is the polarizing potential of the unit, so that the relay trips when $I_S\cos\psi + I_F\cos\lambda$ is positive. The unit has maximum torque when the current is 30 degrees leading the polarizing potential, so that ψ or λ are 30 degrees less than the angle between I_S or I_F and the polarizing potential.

If one refers to Figure 13, treating counterclockwise angles as positive

$$\psi_{12} = \gamma - 60°$$
$$\lambda_{12} = -90° + \phi + \theta - \alpha - 60° + 180°$$
$$= \theta + \phi - \alpha + 30°$$

Similarly

$$\psi_{31} = 180° + \gamma - 60° + 90° = \gamma - 150°$$
$$\lambda_{31} = 180° + \phi + \theta - \alpha - 60° + 90°$$
$$= \theta + \phi - \alpha + 120°$$

The 2–3 relay has no swing component, because $I_{12S} = -{}^1/_2 I_{1S}$; therefore $I_{12S} - I_{1S} = 0$. But

$$\lambda_{23} = 180° - 90° + \phi + \theta - \alpha - 60° - 90°$$
$$= \theta + \phi - \alpha + 120°$$

Hence, with outgoing power, the relay will trip in any phase where one of the following expressions is positive:

Relay 1–2: $K\cos(\gamma - 60°) + \dfrac{\cos(\phi+\theta-\alpha+30°)}{Z_{RA}}$

Relay 2–3: $\dfrac{\cos(\phi+\theta-\alpha+120°)}{Z_{RA}}$

Relay 3–1: $K\cos(\gamma - 150°) + \dfrac{\cos(\phi+\theta-\alpha+120°)}{Z_{RA}}$

where

$$K = \frac{\sqrt{3}\cos\frac{\theta}{2}}{Z_S\cos\left(\frac{\theta}{2}-\alpha\right)}$$

Referring to Figure 13, in a similar manner, with incoming power, that is, considering the B relay

$$\psi_{12} = \gamma - 60°$$
$$\lambda_{12} = 180° - 90° + \phi - \theta + \beta + 30° - 90°$$
$$= \phi - \theta + \beta + 30°$$

Here again $I_{12S} = 0$ and

$$\lambda_{23} = -90° + \phi - \theta + \beta + 30° + 180°$$

that is

$$\lambda_{23} = \phi - \theta + \beta + 120°$$

Likewise

$$\psi_{31} = -180° - \gamma + 30° = \gamma - 150°$$

and

$$\lambda_{31} = 180° - 90° + \phi - \theta + \beta + 30°$$
$$= \phi - \theta + \beta + 120°$$

Hence, the relay will trip in any phase where one of the following expressions is positive:

Relay 1–2: $K\cos(\gamma - 60°) + \dfrac{\cos(\phi-\theta+\beta+30°)}{Z_{SB}}$

Relay 2–3: $\dfrac{\cos(\phi-\theta+\beta+120°)}{Z_{SB}}$

Relay 3–1: $K\cos(\gamma - 150°) + \dfrac{\cos(\phi-\theta+\beta+120°)}{Z_{SB}}$

where

$$K = \frac{\sqrt{3}\cos\frac{\theta}{2}}{Z_S\cos\left(\frac{\theta}{2}-\beta\right)}$$

The expression for phase 2–3 has no load term, because the load components in the faulted phases are in phase and hence cancel out. In the case of phase 1–2 with incoming power the swing component becomes positive and tends to trip when θ exceeds 90 degrees, and the fault component tends to trip when θ exceeds 45 degrees. In phase 3–1 the load component always tends to trip and the fault component to open the mho-unit contacts.

With outgoing power both the swing component and the fault component in phase 1–2 tend to prevent tripping. In phase 3–1 the swing component tends to trip and the fault current to prevent tripping up to $\theta = 90$ degrees.

The worst of these cases is the first one, phase 1–2 with incoming power. The Midian relay trips when there are 30 degrees between the station voltages, that is, $\delta = 30$ degrees, and $\theta = 48$ degrees. From a chart similar to Figure 6, $\gamma = 180$ degrees and $Z_S = 620$ ohms. This is checked as follows:

$$K\cos(\gamma - 60°) + \frac{\cos(\phi-\theta+\beta+30°)}{Z_{SB}}$$
$$= \frac{\sqrt{3}\cos 24°\cos(180°-60°)}{620\cos 15°} + \frac{\cos(72°-48°+8°+30°)}{370}$$
$$= \frac{\sqrt{3}\times 0.914\times(-0.5)}{620\times 0.966} + \frac{0.47}{370}$$
$$= -0.00132 + 0.00127 = -0.00005$$

This shows that the actual point of failure is slightly more than $\theta = 48$ degrees. It is not worth while checking with a slightly larger value however, because only a slight oscillation would be necessary to reach the larger value.

During the system tests double-ground faults were applied on the 66-kv and 132-kv busses at each end of the line with both incoming and outgoing power up to 35,000 kva, and no wrong operations of the mho units were observed. It was not possible at the time to repeat these tests to check the calculated threshold values.

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Oil-Impregnated-Paper High-Voltage Condenser Bushings for Circuit Breakers and Transformers

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Synopsis: For many years shellac or synthetic-resin-coated paper has been used in winding condenser bushings. Two years ago work on the development of oil-impregnated-paper condenser bushings was undertaken. When a shortage of shellac was imminent because of the war, effort to complete the development was greatly increased, resulting in its being completed well ahead of the date originally set. Manufacturing processes and impregnating treatments were developed and bushings built and tested. The processes and treatments are described, and the data obtained from tests on representative bushings are given.

Complete interchangeability for transformer and circuit-breaker bushings has been obtained for current apparatus designs in the voltage ratings in which the bushings are produced. To a large extent, the new bushings are also interchangeable with bushings of older design in the same voltage rating. The entire insulating portion of the bushing is enclosed in porcelain and metal and this enables the bushing to be held in storage without special provisions for keeping it dry.

The oil-impregnated-paper condenser bushings, built for voltage ratings 92 kv to 230 kv, are susceptible to careful control of quality in the processing operations. Exceptionally consistent performance and high dielectric strength are obtained. Consistently low power-factor readings on both hot and cold bushings were obtained. Radio-influence voltage measurements were below proposed standards.

CONDENSER-TYPE high-voltage bushings 92 kv and above are being built with insulating cores of uncoated high-grade paper wound on the conducting stud and impregnated with low-viscosity insulating oil. Previously, the condenser elements were wound from paper coated with adhesive material such as shellac or one of the synthetic resins.

The condenser construction is old in the art of bushing manufacture. Its ability to withstand both current and voltage surges has been demonstrated amply by its use for more than 30 years in both high- and low-voltage bushings. Therefore, the theory of bushing-condenser design is not repeated in this paper.

The oil-impregnated-paper condenser bushings retain the known advantages of uniform voltage gradient, high-capacitance potential tap, mechanical strength, and small external diameter. From these features accrue other values such as small diameter and high efficiency of current transformers and the possibility of securing the maximum of interchangeability between both new and old circuit-breaker and transformer bushings. Complete interchangeability has been attained between transformer and circuit-breaker bushings of 92-kv and higher-voltage ratings in current production, and, although the new oil-impregnated bushings cannot be made interchangeable with all old bushings, they can replace older designs to a greater extent than has been possible heretofore.

The development of oil-impregnated condenser bushings, although accelerated by wartime conditions, has been planned for several years. Plastics and oils were studied. A low-viscosity oil was selected to prevent formation of voids within the condenser at extreme winter temperatures and to facilitate the impregnation process, and also because of a slight superiority in electrical properties of the impregnated paper.[4,7]

The insulation in condenser bushings under normal service voltage to ground, is worked at an average potential stress of less than 50 rms volts per mil. In the 60-cycle withstand test, the gradient is approximately 200 volts per mil. Under surge conditions, with a 1.5 by 40-microsecond full wave, at the basic impulse level, the stress may reach an average value of 450 crest volts per mil of insulation thickness for a few microseconds. Steep-front surge flashovers have been made in the high-voltage laboratory,[1-3] in which the average stress at the time of crest voltage was just under 1,000 volts per mil.

The voltage gradients in these bushings are relatively low compared with those in other applications of oil-impregnated paper insulation. J. B. Whitehead[4] has published accelerated-life-test results for voltage stresses starting at 400 rms volts per mil and increasing 3.12 per cent every four hours until failure. The average failures occurred at about 715 volts per mil, after about 75 hours, in samples comparable to a single layer or step of a condenser bushing wound with 0.005-inch paper. The bushing condensers have an added advantage of being wound from a wide sheet of paper instead of from narrow strips of tape (except that, in the larger sizes, the inner layers more than 100 inches long are helically wound from paper tape).

In paper-insulated oil-impregnated cables,[5] in the same standard voltage ratings as these bushings, the normal operating stress is approximately 140 rms volts per mil. Foust and Scott[7] show that such insulation breaks down at 1,300 to 2,000 crest volts per mil on impulse voltage tests using a 1.5-by-40-microsecond wave.

In oil-impregnated paper capacitors, using capacitor paper and thinner insulating walls, continuous 60-cycle rms gradients of 250 to 300 volts per mil have been used and intermittent d-c gradients up to 1,000 volts per mil.

This experience and test data, substantiated by other laboratory tests omitted for brevity, indicate a large margin of insulation strength in the condenser, even when stressed with the

Table I

Gap	No. of Shots	Corrected Kilovolts	Time to Flashover (Microseconds)	Average Rate of Rise (Kilovolts Per Microsecond)	Effective Rate of Rise (Kilovolts Per Microsecond)
33-inch rod	20	982	0.94	1,045	1,760
		980	0.91	1,070	1,630
42-inch rod	20	1,080	1.6	675	1,080
46-inch experimental	100	1,142	1.84	620	1,220
		1,135	1.75	650	1,250
42-inch rod	20	1,567	0.70	2,240	2,340
42-inch rod	20	1,745	0.61	2,860	3,160

Flashovers occurred sometimes on the gap or bushing alone, but generally the flashover occurred on both bushing and gap.

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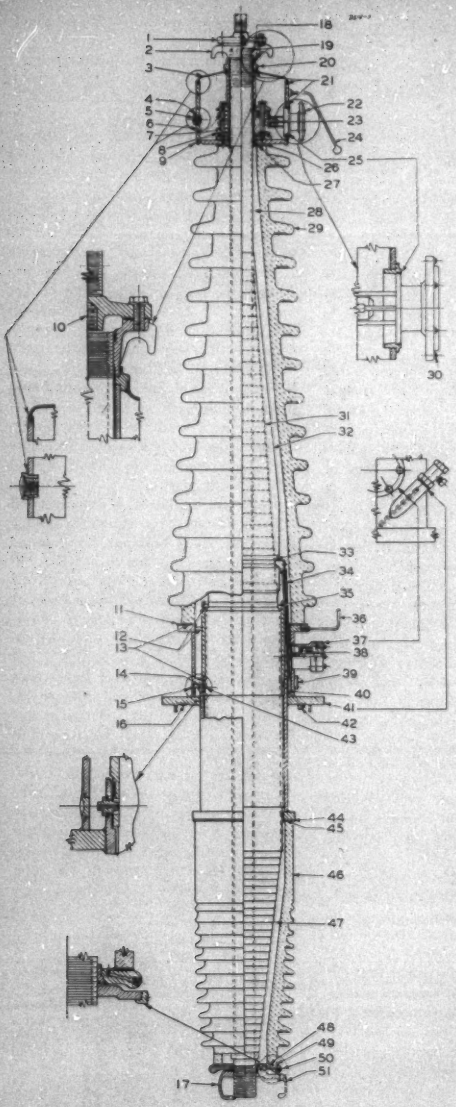

Figure 1. Typical outline of oil-impregnated condenser bushing

1—Adapter cap
2—Nut with lifting lugs
3—Spun copper. Differential expansion taken up by flexing
4—Brazed
5—Pipe plug soldered over
6—Steel shell
7—Gauge for determining spring setting
8—Coil-spring assembly places pressure on all gaskets for upper and lower porcelains. Six springs
9—Welded
10—Connection for fished-through lead for transformer
11—Asbestos Neoprene gasket
12—Grounding straps
13—Cork Neoprene gaskets
14—Stop to limit vertical movement and prevent rotational movement of condenser
15—Low-temperature solder
16—Cork Neoprene gasket for transformer
17—Ball static shield for transformers only
18—Cork Neoprene gasket
19—Low-temperature solder
20—Thimble
21—Brazed
22—Removable magnetic oil gauge—four-inch dial
23—Oil level at 75 degrees Fahrenheit
24—Gap electrode
25—Low-temperature solder—can be unsoldered to remove gauge
26—Asbestos Neoprene gasket
27—Cork Neoprene gasket
28—Upper oil chamber
29—Upper porcelain
30—Gauge dial and pointer assembly can be easily replaced
31—Copper foils
32—Oil-impregnated condenser (oil-filled kraft paper)
33—Voltage tap band
34—Voltage tap connector
35—Ground foil band
36—Gap electrode
37—Voltage tap socket
38—Porcelain
39—Name plate
40—Sampling valve and tubing
41—Steel flange
42—Bevel ring and asbestos Neoprene gaskets for circuit breaker
43—Small hole—connecting passage between upper and lower oil chambers
44—Asbestos Neoprene gasket
45—Cork Neoprene gasket
46—Lower porcelain
47—Lower oil chamber
48—Cork Neoprene gasket
49—Asbestos Neoprene gasket
50—Drain plug
51—If this bushing is used as replacement of different style bushing, use the static shield or ball from the replaced bushing

most severe surges where the average gradient was 1,000 volts per mil.

Successful production of oil-impregnated-paper bushing insulators requires carefully developed and controlled manufacturing processes and treatments. At the same time, this construction is responsive to careful control and treatment during production, resulting in a more uniform product than has been obtained heretofore. A large part of the equipment previously used for winding condensers from coated paper has been adapted, with minor changes, to production of the oil-impregnated condenser. Equipment for vacuum drying and degassing the bushings has been specially developed for this purpose. Oil conditioning and handling equipment likewise is new (Figure 2).

Bushing Construction

Figure 1 shows typical construction of the oil-impregnated condenser bushings, which are built in ratings of 92 to 230 kv inclusive. The conductor is a copper tube upon which the paper condenser is wound and serves as a stay bolt holding the entire assembly together under pressure of compression springs in the cap.

The stud or lead (the copper tube) is prepared by straightening, shot blasting, and coating with an adhesive material. Bare Kraft paper 0.005-inch thick, having a density of 0.82 maximum–0.67 minimum is wound on the stud to the specified diameter. During winding, at precalculated diameters, coated copper-foil sheets are inserted to provide a series of concentric condensers. Each foil is coated on both sides with thermoplastic adhesive which binds the foil to the adjacent layers of paper, and the condenser at intervals of approximately every quarter inch increase in diameter. When the specified number of condenser layers has been wound, a layer of paper treated with adhesive is wound on the outside to bind the condenser structure securely.

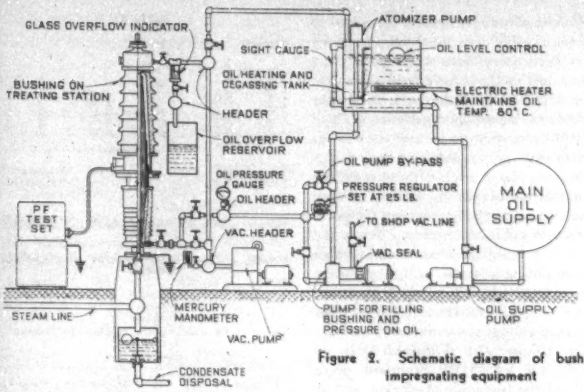

Figure 2. Schematic diagram of bushing impregnating equipment

During the winding operation, the paper is heated to 165 degrees centigrade ±3 degrees centigrade and rolled under tension and pressure. It is then machined in the same manner as the shellac Micarta condenser which it supersedes.

A steel sleeve is pressed on the machined condenser and connected electrically to the outer foil. This sleeve provides a means for attaching and mounting the condenser to the bushing flange, allowing limited movement longitudinally and rotationally between the condenser and the flange, as required for building and for differential expansion and contraction. A fabricated steel flange with provision for a potential tap insulator and oil-sampling valve supports the porcelains which encase both the lower and upper ends of the condenser. Gasketed joints with mechanical stops are provided between the porcelain and metal members. The pressure on all gaskets is equal and is obtained from springs within the cap. The condenser, being permitted to move longitudinally through the flange, within controlled limits, permits use of the same springs to provide pressure on all of the gaskets. All joints in the enclosing parts of the bushing, except the gasketed joints adjacent to the porcelains, are made by silver-alloy brazing or by soldering.

It was found during the impregnating period, when bushings are subjected to hot oil under pressure for several days, that many castings would show leaks, even several days after the treating operation began. Therefore, all metal parts of the bushing which form oil seals are now made from sheet or fabricated material. The insulating condensers are enclosed completely in metal and porcelain so as to remove all possibility of moisture absorption at any time. Oil-level indication is provided by a magnetic-type gauge soldered into the side of the cap. A valve is provided in the flange for obtaining oil samples, if required, and removable plugs in the bottom and top of the bushing permit draining or refilling.

Processing of Bushings

The assembled bushing is sealed and tested for leaks with an internal air pressure of 20 pounds per square inch and the complete bushing immersed in water for 30 minutes. During the test there must be no evidence or appearance of bubbles caused by escaping air. To expedite drying during the vacuum processing, the bushing is baked for approximately 12 hours at 95 degrees centigrade ± 5 degrees centigrade immediately before being connected to the treating system. During processing, the bushing is mounted on a support as shown in Figure 2, and steam at 120 degrees centigrade (approximately 14 pounds per square inch gauge pressure) is admitted to the inside of the copper tube on which the bushing is wound. The top end of the tube is closed and sealed. The steam gives off heat to the bushing, and condensation occurs within the copper tube and is removed from the system through a suitable trap. Connection is made to the vacuum system at both the top and bottom ends of the bushing. An absolute pressure of less than 5 millimeters of mercury is obtained within the bushing. The drying treatment is continued under high temperature and low pressure until degassing is complete and the power factor does not exceed 0.004. When this condition is obtained, a low-viscosity insulating oil, previously conditioned by heating and degassing, is admitted to the bushing at the lower end and permitted to rise until the bushing enclosure is filled completely. Pressure is then applied to accelerate complete saturation of the condenser with oil. Saturation is tested by reading the capacitance of the bushing with a Schering bridge and noting when no further increase occurs. It has been found that the fully treated bushing capacitance increases approximately 44 per cent over the dry bushing capacitance.

Mechanical Tests

Mechanical tests were made on a sample bushing to demonstrate ability to withstand handling, transportation, and service abuses. They are reported in detail in the appendix.

Electrical Tests

Electrical tests made on bushings of two voltage classes are reported in this paper. The first was a 196-kv 1,200-ampere experimental bushing. This bushing differed from standard in two respects:

1. There was no potential tap.
2. The lower porcelain was nine inches shorter than standard.

The short porcelain was used to avoid delaying tests while waiting for the standard porcelain of the new design to be manufactured.

The second bushing tested and described in this paper was rated 138 kv, 1,200 amperes. It was of standard design and materials in all respects.

Test results are given on these two ratings of bushings, because 138 kv is the most widely used transmission voltage, and 196-kv bushings are used on 230/196-kv apparatus where they are subjected to the 230-kv system voltage.

Electrical tests were made to determine if the bushings would meet all AIEE, National Electrical Manufacturers Association, or other electrical requirements. After these requirements were satisfied successfully, tests were continued for the purpose of obtaining information on the reserve insulation strength. An unusually large reserve was shown in both bushings, as indicated in the complete test results given in the appendix, but summarized in the following paragraphs.

196-Kv Bushing Tests

Before making high-potential tests, power-factor and capacitance measurements were made at room temperature

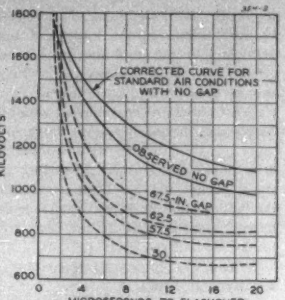

Figure 3. 196-kv experimental bushing flashover curves

Standard rod gap in parallel, 1.5x40-microsecond positive wave

Approximately 40 flashovers for each curve observed

Values of radio-influence voltage that are permissible in high-voltage apparatus have been the subject of study for some years; test methods have been agreed to; and considerable data have been obtained on important apparatus. There is still a question as to how far the industry can go in requiring low radio-influence voltage levels without imposing economic hardship. The form of bushing here discussed is favorable from the point of view of radio interference. This is the result of a bushing construction in which the insulating material, being completely impregnated with oil, is free from voids, and the discharges which produce radio-influence voltage are minimized.

One-Minute Dry Withstand Tests, 60 cycles, 465 kv (AIEE Standard) were made at the beginning of, during, and at the completion of the high-potential test program. The bushing did not give any indication of distress, although both porcelains were broken and considerable damage done to the condenser before the last withstand test was made.

The Standard Impulse Test for bushings of this voltage rating is three shots with a 1.5 by 40-microsecond full wave having a crest value of 900 kv. After the bushing was subjected to the standard test, additional impulse tests were made with positive and negative 1.5x40-waves having crest values ranging from 680 kv to 1,800 kv. A total of 203 impulses was imposed on the bushing. The values provided volt-time impulse-flashover curves shown in Figure 3. Each curve represents approximately 40 shots. In this set of tests, gaps were used in parallel with the bushing for the first 160 tests, as indicated in Figure 3. Forty tests were then run without a gap. In Figure 3 these tests are marked "no gap." When corrected for standard air conditions, the actual impulse-flashover values are indicated by the curve in Figure 3 marked "corrected curve for standard air conditions with no gap." Three 1.5 by 40-microsecond negative full-wave impulse tests were made. The third test broke a skirt of the lower porcelain. To conserve the porcelains for additional testing, gaps were again installed, and 77 steep-front impulse tests were made having crest values from 1,178 kv to 1,850 kv. During this series of tests, both porcelains were broken.

The condenser was apparently unharmed at the end of the tests just described. It was then removed from the porcelain enclosure and left standing with the upper end exposed to air from Friday

Table II

End Dropped	Drop Distance (Inches)	Position of Potential Tap	Number of Drops	Remarks
Top	1 1/8	Up	105	No damage*
Top	1/8	Up	1,100	No damage†
Top	1/8	60 degrees clockwise	1,000	No damage†
Top	1/8	60 degrees counter-clockwise	1,000	No damage†
Bottom	1/8	60 degrees clockwise	1,000	No damage‡
Bottom	1/8	Up	1,000	No damage‡
Bottom	1/8	60 degrees counter-clockwise	3,000	No damage‡
Top	1/8	60 degrees counter-clockwise	2,000	No damage†

* Drop of 1 1/8 inch unjustifiably severe; 1/8-inch drop comparable with similar tests previously made on samples of earlier types of bushings.

† Bottom end rebounded about 1/2-inch high after each drop of top end.

‡ Top end rebounded twice (first bounce 1/16 inch) at each drop of bottom end. Bottom end also rebounded slightly.

Weather	Barometer (Inches)	Temperature (Degrees Fahrenheit) Dry	Wet	Relative Atmospheric Density	Humidity	Humidity Correction Factor	Total Correction Factor
50-inch gap	29.26	66	52	1.008	0.238	1.093	1.084
57.5-inch gap	29.16	76	56	0.980	0.235	1.093	1.115
62.5-inch gap	29.10	82.5	59	0.965	0.248	1.088	1.127
67.5-inch gap	29.10	70	53.5	0.985	0.233	1.093	1.109
No gap	29.24	86	62.5	0.965	0.313	1.071	1.109

(25 degrees centigrade) and at elevated temperature (the entire bushing heated to 80 degrees centigrade). The readings were:

25 degrees centigrade—power factor = 0.0049, capacity = 366 micromicrofarads

80 degrees centigrade—power factor = 0.0076, capacity = 371 micromicrofarads

Comparative power-factor and capacitance measurements were made up to 200 kv, using a high-voltage Schering bridge (see appendix). The readings taken before and at intervals during high-voltage testing showed that the curve of power factor and capacitance versus voltage was practically flat, and also that the bushing condenser was not being damaged appreciably by the tests.

Radio-Influence Voltage measurements were taken at 10-kv steps from 160 kv to 200 kv. No measurements were above 25 microvolts. The same values were read on the test circuit alone and with the bushing connected to the circuit. It therefore seems obvious that the value of radio-influence voltage of the bushing was below that of the circuit alone. At the conclusion of all high-voltage tests, after both porcelains had been destroyed and the condenser badly damaged, readings were taken up to 150 kv. No reading exceeded 150 microvolts.

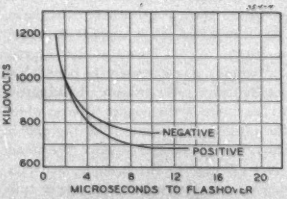

Figure 4. 138-kv bushing flashover curves with 43.2-inch standard rod gap in parallel, 1.5x40-microsecond positive and negative waves

Type-O condenser bushing

Weather	Barometer (Inches)	Temperature (Degrees Fahrenheit) Dry	Wet	Relative Atmospheric Density	Humidity	Humidity Correction Factor	Total Correction Factor
Positive	29.34	85	74	0.965	0.732	0.975	1.012
Negative	29.34	85	74	0.965	0.732	0.975	1.012

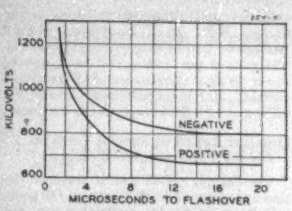

Figure 5. 138-kv bushing flashover curves with 46-inch special gap in parallel, 1.5x40-microsecond positive and negative waves

Type-O condenser bushing, 4¹/₄-inch diameter toroid gap

Weather	Barometer (Inches)	Temperature (Degrees Fahrenheit) Dry	Wet	Relative Atmospheric Density	Humidity	Humidity Correction Factor	Total Correction Factor
Positive	29.36	83	71¹/₂	0.970	0.656	0.990	1.031
Negative	29.32	81	74	0.972	0.770	0.969	0.996

night until Monday morning. The entire condenser was then immersed in a large tank of oil and given 40 impulse shots with a 67.5-inch gap in parallel. Voltages having a crest value of 1,880 kv were attained. This set of tests was followed by 25 steep-front impulses having a crest value of 1,900 kv. At the end of this series of tests, damage was indicated in 18 of the 30 steps in the condenser which, however, successfully withstood a 465-kv 60-cycle test for one minute. More detailed information is given in the appendix.

138-Kv Bushing Tests

Power-Factor and Capacitance measurements were made at 13.8 kv with the inverted Schering bridge. The power factor was 0.0037, and the capacitance was 399 micromicrofarads. High-voltage power-factor tests and capacitance measurements were made with a laboratory-type high-voltage Schering bridge. These measurements began at 47 kv and ended at 150 kv. The power factor at 47 kv was 0.0035, and the capacitance was 362 micromicrofarads. At 150 kv, the power factor was 0.0039, and the capacitance was 362 micromicrofarads. The high-voltage Schering bridge tests were repeated several times during the series of 60-cycle and impulse tests. No variation in these values occurred throughout the series of tests, indicating that the condition of the bushing at the end of the tests was substantially the same as at the beginning.

Radio-Influence Voltage measurements were made at several voltages up to 150 kv. No reading exceeded 150 microvolts, indicating that the radio-influence voltage was well within any limits proposed for bushings of this voltage rating.

Dry Flashover Tests. After the standard AIEE one-minute dry test (335 kv), had been made, it was decided to develop the dry flashover strength of the bushing. Ten flashovers were made from 403 kv to 438 kv.

Wet 60-Cycle Flashovers were made following the ten-second wet withstand test of 275 kv. Ten flashovers were made with voltages ranging from 340 kv to 369 kv.

Volt-Time Impulse Tests were made at the standard value of 650 kv with a 1.5x40-microsecond full wave. To obtain further data on the actual insulation strength of the bushing, additional impulse tests were made with positive and negative waves. A total of 160 positive and negative wave impulses were made with a 1.5 by 40-microsecond wave, both full and chopped, from the results of which Figures 4 and 5 were drawn. These tests were followed by 180 steep-wave-front flashover tests. Crest voltages ranged from 982 kv to 1,745 kv. Additional data on this series of tests are given in the appendix.

The insulation of the bushing was indicated to be unharmed at the end of this series of tests, and the bushing was taken to another laboratory for mechanical tests which are described in the appendix.

Conclusions

High-voltage outdoor-type condenser bushings have been built in which the insulation is oil-impregnated paper. The bushings are usable and interchangeable on either circuit breakers or transformers of current design and in nearly all cases can be used to replace bushings of earlier design. The bushings are assembled completely and treated in the factory, then permanently sealed before shipment. They are designed to pass through bushing-mounting flange openings and current transformers without the dismantling of any parts, since the entire condenser structure is hermetically sealed in metal and porcelain. No special storage requirements for protection against weather or atmospheric conditions are required. The design provides for emergency operation of a bushing over a considerable period of time, even though one of the porcelain casings might be broken or destroyed. Electrical tests required by the industry have been met with a wide margin of safety. Very high puncture strength has been demonstrated by the fact that no damage was done to the insulating members over a long series of electrical tests until after the enclosing porcelains had been completely destroyed. Power-factor measurements at both room temperature and elevated temperature are very low. Radio-influence voltage measurements were well within limits proposed.

The tests reported in this paper were made on new bushings under good conditions. Bushings in service cannot be kept clean at all times and should not be expected to maintain continuously the high values obtained in these tests.

Since 1936 the Detroit Edison Company has rebuilt a large number of 132-kv condenser bushings using the old condensers. Before the rebuilding, the varnish was removed, and the condensers were impregnated with insulating oil. The satisfactory service record of these rebuilt bushings, with the limitations of old materials, is convincing evidence that the use of oil-impregnated paper condensers is a valuable improvement in bushing construction.

While the construction and processing of the rebuilt bushings and those described in this paper are not identical, the authors received valuable encouragement and stimulation from the early work done by the Detroit Edison Company engineers in rebuilding bushings.

Appendix

Detailed Report of Special Tests on 196-Kv Experimental Bushing

Test 1—High-Voltage Schering-Bridge Tests at 200 Kv. Comparison standard capacitor comprising a stack of coupling capacitors, as read by 13.8-kv inverted Schering bridge; 0.0024 power factor, 642 micromicrofarads.

Apparent power factor and capacitance of bushing, mounted in large closed-top testing tank of oil, at 200 kv, assuming comparison standard power factor and capacitance to remain constant: 0.00305 power factor, 297.5 micromicrofarads.

This reading was rechecked, with insignificant small variations, at frequent intervals during the surge-testing program, and this served to prove that no appreciable damage was being inflicted on the bushing condenser by the tests.

This reading neglects the unknown difference between the capacitance of the comparison standard as read by the inverted Schering bridge and as used in the conven-

tional high-voltage bridge circuit, because of the external capacitance to ground being included in the former and excluded in the latter.

Test 2—Radio-Influence Voltage Measurements to 200 Kv. Test made with standard radio-influence measurement circuit,[9,9] using 220-kv coupling capacitor.

Applied 60-Cycle Kilovolts	160	170	180	190	200
Microvolts, with bushing	10	25	15	20	15
System, without bushing	10	25	15	20	15

Test 3—Dry Withstand Test, 465 kv, 60 cycles, one minute—successful. (Schering-bridge check test at 200 kv.)

Test 4—Impulse-Flashover Curve, kilovolts versus microseconds 1.5 by 40 microseconds; positive wave, 50-inch standard rod gap in parallel. 680 kv to 1,150 kv at 2 microseconds. See Figure 3 (40 shots)—successful. (Schering-bridge check test at 200 kv.)

Test 5—Impulse-Flashover Curve, kilovolts versus microseconds 1.5 by 40 microseconds; positive wave, 57 1/2-inch standard rod gap in parallel. 770 kv to 1,800 kv at 1.2 microseconds. See Figure 3. (40 shots)—successful.

Test 6—Impulse-Flashover Curve, kilovolts versus microseconds 1.5 by 40 microseconds; positive wave, 62 1/2-inch standard rod gap in parallel. 820 kv to 1,650 kv at 2 microseconds. See Figure 3. (40 shots)—successful.

Test 7—Impulse-Flashover Curve, kilovolts versus microseconds 1.5 by 40 microseconds; positive wave, 67 1/2-inch standard rod gap in parallel. 900 kv to 1,650 kv at 2 microseconds. See Figure 3 (40 shots)—successful. (Schering-bridge check test at 200 kv.)

No damage of any kind to the bushing resulted from any of the foregoing tests.

Test 8—Impulse-Flashover Curve, kilovolts versus microseconds 1.5 by 40 microseconds; positive wave without gap in parallel. Approximately 40 shots. 940 kv to 1,770 kv at 0.75 microsecond. See Figure 3—successful. (Schering-bridge check test at 200 kv.)

In test 8, a small piece was broken off the edge of one skirt near the middle of the weather casing.

Test 9—Impulse-Flashover Curve, kilovolts versus microseconds 1.5 by 40 microseconds; negative wave without a gap in parallel—test not completed. (Schering-bridge check test at 200 kv.)

After three shots, a skirt of the lower porcelain was broken by flashover in the tank oil, and negative-wave flashover tests were discontinued. The standard porcelain for this 196-kv bushing is 36 1/4 inches long, but to avoid waiting for manufacture of the correct porcelain, this experimental bushing had been built with a porcelain 27 1/8 inches long. Therefore, performance of this lower porcelain was not pertinent. With the broken lower porcelain, the testing was resumed.

Test 10—Steep-Front Impulse Test, positive wave, 63-inch standard rod gap in parallel. Ten shots 1,178 kv (uncorrected). Effective rate of rise kv per microsecond = 870. Flashed on gap.

Test 11—Same as Test 10 except 1,709 kv (uncorrected), and effective rate of rise = 3,200 kv per microsecond. Ten shots. Eight shots flashed gap and two shots flashed both gap and bushing.

Test 12—Same as Test 11 except 1,850 kv (uncorrected) and 3,360 kv. Per microsecond effective rate of rise. 57 shots. All shots flashed both gap and bushing.

Noises were heard in the test tank on 36th and 37th shots, indicating further shattering of the previously broken lower porcelain. Bridge readings were taken and found to be normal. Testing was resumed on the following day. On the 56th shot, a small piece was broken off the top end of the top porcelain. The 57th shot was taken, and a large piece was knocked out of the upper porcelain extending down to eighth skirt from the top. Apparently the bushing had lost oil because of breakage of lower porcelain, since none was found in weather casing when it broke.

The bushing was temporarily lifted above the test tank for inspection, and the lower porcelain was found badly shattered.

Bridge readings were taken at 200 kv and indicated the condenser to be unharmed. (0.0034 power factor; 297.5 micromicrofarads.)

The bushing was removed from the test tank.

The porcelains and flange were completely removed and the condenser examined. Slight markings were observed on the surface of the lower end, indicating that after the lower porcelain was broken, at least one flashover had occurred over the surface of the lower end of the condenser.

The unprotected condenser was left standing from Friday night until Monday morning with the upper end exposed to air, the lower end, from the normal flange location down, was immersed in oil. Without further treatment, test 13 was made.

Test 13—The condenser was suspended on a string of strain insulators in a 20-foot-diameter oil tank with the outer foil grounded. To reduce voltage disturbances over the surface of the oil, the cap was used as a shield on the upper end of the stud, about half of the cap being under oil. The condenser was given the one-minute dry 60-cycle withstand test of 465 kv. Results—successful.

Test 14—Still in oil tank, as in test 13, an impulse curve, kilovolts versus microseconds, to flashover was run with a 1.5 by 40-microsecond positive wave and a 67 1/2-inch rod gap in parallel to 1,880-kv crest. About 40 shots were taken. The curve corresponded closely to the curve for the 67 1/2-inch gap in Figure 3. Results—successful.

Test 15—With the same setup as for test 14, 25 shots were taken with a positive wave rising to 1,900-kv crest. Effective rate of rise 3,360 kilovolts per microsecond. During the series, some bubbles rose, indicating breakdowns were occurring either over or through the condenser insulation. On the 21st to 25th shots, the gap did not flash. Inspection showed 18 of the 30 steps in the condenser damaged.

Test 16—The condenser was again suspended in the tank as for tests 14 and 15. 465 kv, 60 cycle was applied for one minute. The badly damaged condenser passed the regular 60-cycle withstand test.

Test 17—The condenser was unwound, and all the breakdowns were observed to have occurred at the ends of the copper foil cylinders, some at the top and some at the bottom end. Each breakdown burned through or flashed over one to three steps. The ends of the bushing had been exposed to the air after the removal of the porcelain casings. The paper was found thoroughly saturated with oil throughout the condenser.

Detailed Report of Special Tests on 138-Kv 1,200-Ampere Bushing

The bushing tested was of standard design and materials in all respects. The processing equipment for production was not completed, and processing was done on experimental equipment. Tests as described in the following were made successfully:

Test 1—Bushing Mounted in Test Tank, room temperature:

(*a*). 13.2-kv inverted Schering bridge = 0.00375 power factor
Capacitance = 399 micromicrofarads

(*b*). High-voltage Schering bridge 47 kv = 0.0035 power factor
Capacitance = 362 micromicrofarads

(*c*). 150 kv = 0.00395 power factor
Capacitance = 362 micromicrofarads

Test 2—Dry 60-Cycle Flashovers (corrected to standard atmospheric conditions):

438 kv—411 kv—438 kv—432 kv—418 kv
426 kv—430 kv—416 kv—403 kv—410 kv

Test 3—Wet 60-Cycle Flashover (corrected kilovolts):

340 kv—353 kv—353 kv—350 kv—357 kv
362 kv—369 kv—357 kv—353 kv—359 kv

Precipitation—0.2 inch per minute
Water pressure—40 pounds per square inch
Resistivity—7,000 ohms per inch cube

Test 4—Schering-Bridge Test to 150 kv.

Test 5—Time to Flashover Impulse Curve with special toroid gap set at 46 inches in parallel, to flash at 670 kv, 1.5 by 40-microsecond positive wave—40 shots up to 1,200 kv. See Figure 5.

Test 6—Time to Flashover Impulse Curve with standard rod gap set at 43.2-inch (700 kv) 1.5 by 40-microsecond positive wave, 40 shots up to 1,200 kv. See Figure 4.

Test 7—Same as Test 5 except with negative wave. See Figure 5.

Test 8—Same as Test 6 except with negative wave. See Figure 4.

Test 9—Schering-Bridge Test at 150 kv indicated no damage.

Test 10—Steep Wave-Front Flashover Tests. For typical oscillograph data see Table I.

Test 11—Schering-Bridge Tests up to 150 kv, together with inspection, showed the condition of the bushing to be the same as at the beginning of the test program.

Drop Tests on 138-Kv 1,200-Ampere Bushing

Bushing horizontal, supported on fulcrum at one end and motor-operated lifting and dropping mechanism at other. Drops 21.5 times per minute (1,290 per hour). See Table II.

Elastic Bending Deflection of Bushing (1/8-Inch Drop)	At Top End of Flange	At Bottom End of Flange
When dropping top end	1/8 inch	1/8 inch
When dropping bottom end	5/16 inch	1/8 inch

Performance Requirements for Relays on Unusually Long Transmission Lines

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Synopsis: Analysis of fundamental bases of relaying made as part of the engineering for the 270-mile 154-kv interconnection between systems of Nebraska Power Company and Kansas Gas and Electric Company reveals that, of current, phase angle, impedance, and impedance angle, none alone offers satisfactory discrimination among open-circuit, short-circuit, and load conditions. Combination of input-impedance magnitude Z and impedance angle $\psi = \tan^{-1} X/R$ is studied by means of "impedance circle diagrams" of the interconnecting circuit. On these diagrams is charted the dynamic behavior of the interconnected systems during faults and surges of synchronizing power. The desirable areas of trip and no trip are mapped, and general specifications for the performance of relay systems are presented in terms of impedance magnitude and angle, $Z \angle \psi$. Thereby full advantage can be taken of all possible synchronizing power inherently available over the interconnection and at the same time faults and approach of out-of-step condition can be recognized properly.

RE-EXAMINATION of fundamental principles of transmission-line relaying for phase protection and the development of advanced methods for calculating and specifying relay performance for long lines and interconnections have been included in the engineering of a 270-mile 154-kv interconnection between systems of Nebraska Power Company and Kansas Gas and Electric Company.[1] This has led to development of new long-line-type relays described in a companion paper.[2] Installation and test of these relays under conditions of actual operation are described in another companion paper.[3]

The complete relay requirements for this interconnection are quite special, because the transmission line is unusually long; transformers are connected as parts of the line between terminal breakers, and automatic instantaneous reclosure of circuit breakers is employed to maintain synchronism after faults without benefit of other parallel ties.

Bases for Relaying

As introduction to the problems of relaying this transmission circuit, some of the principal bases of modern relaying and their applicability to long-line interconnections are reviewed.

Current Magnitude and Phase-Angle Bases

Figure 2 indicates as a function of length the magnitude of current which may be expected at the sending end of an open-wire transmission line with construction suitable for 154-kv 60-cycle operation for open circuit, for a representative load, and for short circuit. Study of these curves reveals that there is little or no hope of attaining discrimination between load and short circuit by measurment of current magnitude on lines much in excess of 100 miles in length. This virtually rules out consideration of overcurrent relays for long lines. On the 270-mile line under study, there would be absolutely no margin since the current on load swings exceeds the short-circuit current for faults at the far end of the line. It should be noted also that the line-charging current is nearly equal to the mininum short-circuit current.

In this discussion, a representative load is assumed to be an impedance equal to the characteristic impedance or surge impedance of the line,[4] $Z_o = \sqrt{z/y}$. However, as explained in the paragraphs which follow, momentary requirements for transfer of synchronizing power between large systems easily may result in tie-line current considerably greater than surge-impedance load and even in excess of far-end short-ciacuit current.

The phase-angle function in transmission-circuit performance and its relation to relaying can be studied conveniently by beginning with the power circle diagram representing power input to the circuit terminal at the relay location. This diagram is plotted in Figure 3 from the sending-end power equation 1

$$P_s = \frac{E_s^2 \cdot D}{B} \angle(\Delta - \beta) - \frac{E_s E_r}{B} \angle(\delta_{rs} + \beta)$$

The form of this equation, and the notation used, are explained fully in Appendix I.

The first term of this equation depends only upon the circuit constants and the voltage E_s at the near end or sending end

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Deflection Tests of 138-Kv 1,200-Ampere Bushing

Bushing mounted vertically by its flange. Sidewise stress applied, and deflection measured to left and to right, seven times each, first at top end and then at bottom end of bushing. Deflections apparently were entirely elastic up to 220 pounds maximum applied.

Deflection per 100 pounds side stress:
Top end—0.00625 inch. Bottom end—0.0052 inch.

Vibration Test

Motor with flywheel unbalanced 0.474 pound-foot, attached to top of bushing, was run 84 hours at 1,300 rpm, exerting a centrifugal force of 273 pounds, vibrating the top of the bushing to a deflection of approximately 0.014 inch from the center line. No oil leak or other damage resulted.

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8. Methods of Measuring Radio Noise, Joint Co-ordination Committee on Radio Reception of Edison Electric Institute, National Electrical Manufacturers Association, and Radio Manufacturers Association, 1940. EEI Publication G9, NEMA Publication 107, RMA engineering bulletin 32, February 1940.

9. Instruments and Methods of Measuring Radio Noise, C. V. Aggers, Dudley E. Foster, C. S. Young. AIEE Transactions, volume 59, 1940, March section, pages 178–87; Figure 14.

of the circuit and defines the location of the center 0′ of the power circle. The second term defines the magnitude and direction of the radius of the power circle.

When $E_r < DE_s$, the power circle radius E_sE_r/B becomes less than E_s^2D/B, which is the distance 0–0′ of the center to the origin, then the steady-state side of the locus P_s lies between the origin 0 and the center of the power circle 0′. With these conditions, the power-factor angle θ lies in the same general direction at normal loads as it does for short circuits on the line.

A numerical example will make this effect clear. For a line about 150 miles long, of uniform symmetrical construction and without terminal transformers, $D=A=0.95$ (see Figure 8). Assume first that $E_r=DE_s$, which means that far-end or receiving voltage is 95 per cent of the near-end or sending voltage. This is a normal condition. The power circle for this condition passes through the origin of the diagram ($P=0$, $Q=0$). For zero power flow ($P=0$), the power-factor angle θ is indeterminate. For small flow of power from the bus to the line ($P>0$), θ is nearly equal to $90-\beta+\Delta$ degrees. For a small reverse flow of power ($P<0$), θ is slightly greater than $270-\beta+\Delta$ degrees. This is a change of nearly 180 degrees in the value of θ for a very small change in load over the line which may be a tie between two systems operating in synchronism.

Next consider what happens upon a change in the relative voltage levels at the two ends of this same line. Assume now that $E_r=0.90E_s$. Since $E_r<DE_s$, the power circle for this condition crosses the vertical axis Q $-Q$ *below* the origin. For condition of no power flow ($P=0$), the power-factor angle θ is 270 degrees, meaning that the near-end or sending system is supplying reactive volt-amperes ($-Q$) to the line and to the far-end or receiving system.

Assume last that $E_r=E_s$. Since $E_r>DE_s$, the power circle for this condition crosses the vertical axis Q $-Q$ *above* the origin. For the condition of no power flow ($P=0$), the power-factor angle is 90 degrees, meaning that the near-end or sending system is obtaining reactive volt-amperes (Q) from the line equal to the charging kilovolt-amperes of half the line.

From this example, it may be seen that the power-factor angle θ may swing to any position within a complete circle of 360 degrees under normal load conditions. It therefore cannot be used alone as basis for discrimination between load and fault conditions.

To complete this analysis of phase angle, it is necessary also to investigate cases of short circuit, open circuit, and loads approaching stability limits.

Points corresponding to open circuit at the far end are not readily plotted on the near-end or sending power circle diagram until the sending-end power is determined from some other equation. The power for this condition is $P_s=E_s^2(C/A)$, which is the charging kilovolt-amperes of the circuit. For uniform open-wire lines, this falls in the first quadrant of the power circle diagram for all lengths up to $^1/_4$ wave length, or nearly 760 miles for 60-cycle power lines having low-resistance conductors. Thus the power-factor angle θ for this open-circuit condition on such lines is always less than 90 degrees and for most lines less than 600 miles long is very near 90 degrees.

For a short circuit at the far end of a circuit ($E_r=0$), the power P_s at the end is found directly from equation 1,

$$P_s=\frac{E_s^2 D}{B}\,/(\Delta-\beta)\quad-\frac{E_sE_r}{B}\,/(\delta_{rs}+\beta).$$

Since $E_r=0$, the second term of this equation disappears, and the power is the first term which locates the *center* of the power circle 0′. Since all such centers for all values of E_s and for all lengths of uniform lines up to very nearly $^1/_4$ wave length, say to 700 miles for 60-cycle power lines having low-resistance conductors, fall in the fourth quadrant, the power-factor angle θ for short circuits on such lines is always between 270 and 360 degrees and is $/(\Delta-\beta)$, corresponding to the length of line to the point of fault.

For analysis of cases near the stability limits of a circuit, it is necessary to refer again to the power circle diagram and power equation. For any pair of values of E_s and E_r, there is one near-end or sending power circle. The maximum power ($P_s$max) which can be put *into* the circuit from the near-end bus at these voltages is specified by a tangent to the power circle drawn to the right-hand side of, and parallel to, the Q $-Q$ axis. The maximum power ($-P_s$max) which can be taken *from* the circuit into the same bus is specified by a similar parallel tangent drawn to the left-hand side of the Q $-Q$ axis.

These two values of power ($P_s$max) and ($-P_s$max) are not steady-state power limits, as might be thought at first glance. The true steady-state power limits for an interconnection established by such a circuit would ordinarily be less than the values thus indicated, depending upon characteristics of the systems interconnected.[5] However, power loads of these magnitudes may be imposed momentarily on interconnection circuits during power swings following system disturbances. Figure 5 illustrates the moment-to-moment changes in angle between two systems and the two terminal voltages of the interconnecting circuit during a system disturbance as obtained from an a-c network analyzer.[6] The angle δ_{rs} is the link or factor connecting this figure with the power circle diagram, Figure 3. It is the angle between the terminal voltages E_r and E_s and must not be confused with either the phase angle θ between current and voltage or the impedance angle $\psi=\tan^{-1}(X/R)$, used in power and impedance diagrams respectively. This angle δ_{rs} is so important in the subsequent discussions that calibration scales of it are included in many of the figures, and diagrams are included for the purpose of identifying corresponding points as related by this angle throughout these discussions.

Referring again to the power limits on the power diagram, Figure 3, it is seen that on the upper or stable half of those

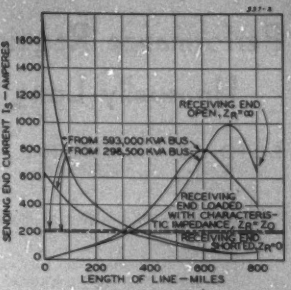

SENDING END CURRENT Is — AMPERES
LENGTH OF LINE — MILES
RECEIVING END OPEN, Zr = ∞
FROM 593,000 KVA BUS
FROM 298,500 KVA BUS
RECEIVING END LOADED WITH CHARACTERISTIC IMPEDANCE, Zr = Zo
RECEIVING END SHORTED, Zr = 0

Figure 2. Current input to line from 154-kv bus as a function of length and far-end terminal load

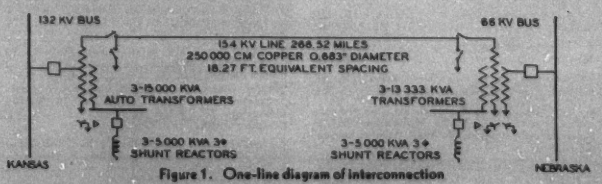

132 KV BUS
66 KV BUS
154 KV LINE 268.52 MILES
250 000 CM COPPER 0.683" DIAMETER
18.27 FT. EQUIVALENT SPACING
3-15 000 KVA AUTO TRANSFORMERS
3-13 333 KVA TRANSFORMERS
3-5 000 KVA 3φ SHUNT REACTORS
3-5 000 KVA 3φ SHUNT REACTORS
KANSAS
NEBRASKA

Figure 1. One-line diagram of interconnection

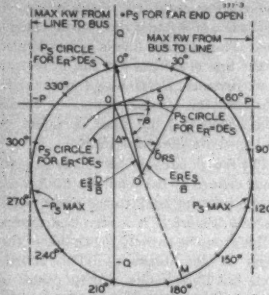


Figure 3. Construction of sending-end power circle diagram from equation 1

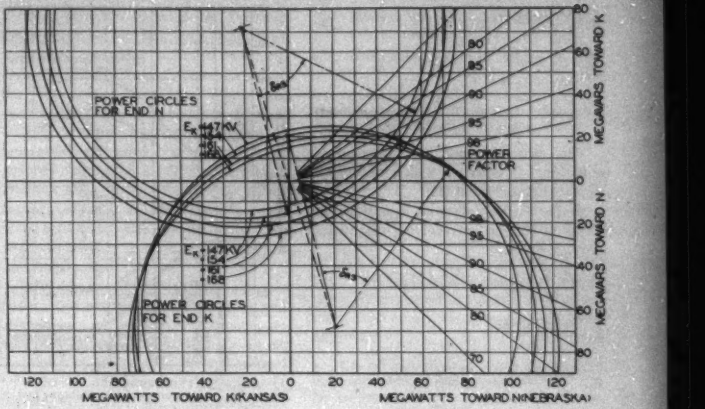


Figure 4. Power circle diagram of the 154-kv interconnection for condition $E_n = 154$ kv

power circles which enclose the origin 0, that is, circles corresponding to $E_s > DE_r$, the phase angle θ swings continuously in one direction through more than 180 degrees as the power simultaneously swings through its full range from ($P_s$max) to ($-P_s$max). For fixed near-end voltage E_s and at one or both of the loads, ($P_r$max) and ($-P_r$max), the kilovolt-amperes and the current I_s measured at the near-end terminal of the circuit are greater than the kilovolt-amperes and current at the same terminal in case of short circuit at the far end.

The very wide range of power-factor angles θ and the lack of discrimination between magnitude of load and fault current previously discussed make over-current, directional, and volt-ampere relay elements unsuitable for the phase-to-phase protection of long lines when used alone, in combination with each other, or in combination with impedance-magnitude elements. This is likewise true for any tie circuit whether long or short, if the impedance of the tie is large compared with that of the systems. In other words, it is true in any case where the synchronizing power required to hold systems in step causes large angular separation (δ_m) between terminal bus voltages.

Input-Impedance Magnitude and Angle

It is most helpful and enlightening also to look at the general transmission circuit from the impedance viewpoint, which is probably better understood by communication engineers than by most power engineers. The 60-cycle input impedances of uniform lines with a conductor size and spacing suitable for 154-kv operation are shown for all lengths from 0 to 800 miles in Figures 6 and 7. The three curves of Figure 6 give the magnitude of sending-end impedance with receiving-end open-circuited, loaded with surge impedance $Z_o = \sqrt{z/y}$, and short-circuited respectively. The three curves of Figure 7 similarly give the angles $\psi = \tan^{-1}(X/R)$ of these same impedances.

Study of Figure 6 reveals that impedance magnitude alone, or measurement of ohms, does not give a good basis for successful discrimination between open, load, and short-circuit conditions close to the far ends of radial-feeder circuits having electrical length corresponding to more than about 200 miles of open-wire line. In contrast to this conclusion, study of Figure 7 shows that angle of the input impedance is radically different, depending upon far-end conditions. This suggests that measurement of *circuit-impedance angle*, $\psi = \tan^{-1}(X/R)$, should provide a basis upon which successful discrimination can be made between normal and fault conditions and upon which relays can be designed for long lines, possibly up to 600 miles in length. A little further consideration, however, indicates that this basis may also have limitations. The derivations of the impedance formula given in Appendixes II and III indicate that, for each point on the power circle diagram of Figure 3, there is a corresponding impedance magnitude and, further, that the impedance angle $\psi = \tan^{-1}(X/R)$ is the conjugate of the power-factor angle θ. We have already discussed limitations of power-factor angle θ as a relay quantity and, because of the conjugate relation, can infer that some of the same limitations might apply to the impedance angle ψ.

Combinations of impedance magnitude, impedance angle ψ, and impedance components present possibilities as bases for relaying which must be explored. For analysis of these, it is necessary, or at least very desirable, to have circuit characteristics and performance completely expressed in chart form on resistance and reactance co-ordinates.[7]

Construction and Interpretation of Impedance Circle Diagrams

There are certain well-known advantages of impedance as a basis for relaying. It is independent of system voltage, and except in special cases, is independent of the number and location of generators in service, and is primarily dependent only upon circuit constants. Hence it was decided to study further the possible combinations of impedance magnitude and angle to determine the performance which would be required of impedance and reactance relay elements to protect properly the proposed circuit and to find what modifications, if any, would be necessary in conventional relay elements.

In this attack on the problem, it was desirable to obtain general formulas for the sending- and receiving-end impedances in terms of the *ABCD* general circuit constants and the sending and receiving voltages. With this goal in mind, the following equations for near-end or sending-end impedance in terms of the circuit constants and voltages were used:

$$P_s = \frac{E_s^2 \cdot D}{B} / (\Delta - \beta) - \frac{E_s E_r}{B} / (\delta_{rs} + \beta)$$

(see Appendix I) (1)

$$Z_s = \frac{(\text{conj } E_s)\cdot E_s}{P_s} \qquad (2)$$

$$Z_s = \frac{D\cdot B}{D^2-(E_r/E_s)^2}/(\Delta-\beta) - \frac{B(E_r/E_s)}{D^2-(E_r/E_s)^2}/(\phi-\beta) \qquad (3)$$

This was obtained by substituting equation 1 in equation 2 as is developed in Appendixes II and III.

Similarly the following equations in terms of far-end or receiving quantities also are useful.

$$P_r = \frac{E_s\cdot E_r}{B}/(\delta_{rs}-\beta) - \frac{E_r^2\cdot A}{B}/(\beta-\alpha) \qquad (4)$$

$$Z_r = \frac{(\text{conj } E_r)\cdot E_r}{P_r} \qquad (5)$$

$$Z_r = \frac{B\cdot(E_s/E_r)}{A^2-(E_s/E_r)^2}/(\phi+\beta) - \frac{A\cdot B}{A^2(E_r/E_r)^2}/(\beta-\alpha) \qquad (6)$$

This equation 6 is companion to equation 3 and is derived by the same method as given in Appendixes II and III.

Symbols appearing in the preceding equations and elsewhere in this paper are identified in Appendix VIII.

From a relay standpoint, equation 3 is of first interest, because it defines the impedance of a protected circuit as "seen" by relays at the near-end terminal of that circuit. Equation 6 is also of interest but is of less immediate significance, because a diagram plotted from equation 3 gives similar results.

Equation 3 when plotted on impedance co-ordinates is represented by a family of circles as in Figure 9. The mathematical relations between these circles and those of the power circle diagrams, Figure 3, are developed in the appendixes. The derivation of the impedance, equation 3, shows that the center of each circle representing a given ratio of terminal voltages E_r/E_s lies on line 0–0 (Figure 9) passing through the origin ($R=0$, $X=0$) at an angle $/(\beta-\Delta)$ with the R–R axis. Five such circles are of particular interest in this discussion. These are the ones corresponding to two general and three special values of the ratio E_r/E_s, as follows:

$$E_s=0,\ \frac{E_r}{E_s}>D,\ \frac{E_r}{E_s}=D,\ \frac{E_r}{E_s}<D,\ \text{and}\ E_r=0$$

The first of these circles which should be examined is one in which the near-end or sending voltage $E_s=0$. In this case ratio $E_r/E_s=\infty$. This corresponds to condition of short circuit at the location of the relays. Since impedance "seen" by the relays is $Z_s=0$, the circle is a point which coincides with origin 0_1.

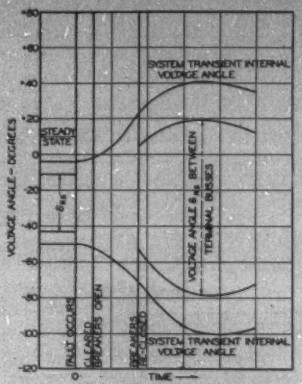


Figure 5. Swing curves of bus voltages and of equivalent internal voltages of generators during tripout and reclosure of interconnecting line

The second circle falls in the general group defined by condition $E_r/E_s>D$. (Referring back to the power circle diagram Figure 3, it is found that this condition defines power circles which enclose the origin.) By plotting one of this general group of circles, it is found that the center lies on the line 0–0 *below* the origin of the diagram, for example at 0_3. One particular case in this group of circles is that for which $E_r=E_s$. In this case, the distance from the center 0_3 to the origin of the diagram is $(D\cdot B)/(D^2-1)$ and the radius is $B/(D^2-1)$.

The third circle of interest is the special case in which $E_r/E_s=D$. In this case (reference to the power circle diagram, Figure 3, reveals that the corresponding power circle passes through the origin of the diagram indicating one point of zero

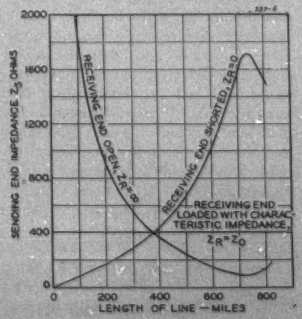


Figure 6. Magnitude of 60-cycle input impedance of a line suitable for 154-kv operation as a function of length and far-end terminal load

power), the circle has diameter of ∞ and radius of ∞ and is therefore a straight line. This straight line is perpendicular to the line of centers 0–0 and intercepts it at distance $B/2D$ above the origin. However, this location cannot be found from equation 3 but must be found as explained in a later paragraph.

The fourth circle is one in the general group defined by the condition $E_r/E_s<D$. (Again referring back to the power circle diagram, Figure 3, it is seen that circles of this group lie entirely to one side of the origin of the diagram.) This fourth circle has finite radius and its center is located on the line of centers 0–0 *above* the origin, for example, at 0_4.

The fifth of these circles is the case where $E_r=0$, corresponding to short circuit at the far end of the line. This circle has no radius and is therefore a point. Its location is on the line of centers 0–0 at distance B/D upward from the origin at 0_5. For convenience this point may be called the far end of the circuit, and the origin 0_1 can likewise be called the near end.

In plotting these circles, the intersection of each with the line of centers 0–0 on the side nearest to the origin 0_1 is of greatest importance. Since these intersections are obtained from the impedance equation 3 as the difference between two quantities which may each be quite large, infinite in one case, it is often desirable to locate these intersections by other more accurate means and then to make the circles pass through these points by slight adjustments in location of the corresponding center or radius if necessary.

Referring back to the power circle diagram, Figure 3, the corresponding point in that diagram is located at M where power circle P_s crosses the line of centers 0–0′ extended. The power P_s at that point has scalar value equal to the *sum* of the radius, and the distance from the origin to the center 0–0′ which sum is $|P_s|_m=(E_s^2\cdot D)/B+E_sE_r/B$. The impedance corresponding to $|P_s|_m$ is therefore $E_s^2/|P_s|_m$. A numerical substitution of values corresponding to either actual or per-unit voltages permits easy calculation of this impedance which is then used to locate the intersection in question on the impedance circle diagram, Figure 9. It should be noted that all such intersections fall between the points 0_1 and 0_5.

As indicated in the appendixes, the authors have found no satisfactory way of relating the angle ϕ appearing in the impedance equation 3 to the angle δ_{rs} between sending- and receiving-end voltages. To date, the impedance circle diagrams similar to Figure 9 used in their calculations have all had these points

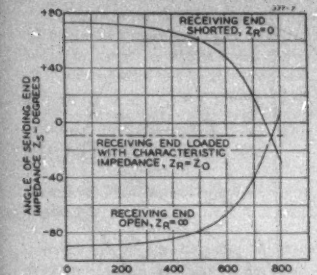


Figure 7. Angle of 60-cycle input impedance of a line suitable for 154-kv operation as a function of length and far-end terminal load

representing various values of δ_{rs} individually computed and located by the following method.

The impedance angle $\psi = \tan^{-1}(X/R)$ appearing on the impedance circle diagram, Figure 5, is the conjugate of the corresponding power-factor angle θ appearing on the power circle diagram. These angles θ are measured for each of several desired values of δ_{rs} on appropriate power circles of diagrams similar to Figure 3 and transferred to the corresponding impedance circle diagrams by locating the intersections of lines Z_s extending from the origin at the conjugate angles ψ and the corresponding impedance circles as in Figure 9.

Locus of Impedance During System Disturbance

If the impedance circle diagram, Figure 9, is used, it is quite enlightening to follow the dynamic behavior of an interconnection during a power swing as it is represented by the swing curves of Figure 5. Prior to system disturbance, the angle δ_{rs} is relatively small, as can be determined from load and terminal voltages by referring to the appropriate power circle diagram similar to Figure 4. Assume for the moment that the direction of the power flow is *from the bus* to the interconnecting circuit at the location of relays. For purposes of this discussion, we may assume the impedance "seen" by the relays to be at A on Figure 9. Upon occurrence of a short circuit on the interconnecting circuit close to the far end, the impedance instantly assumes a value closely corresponding to $E_r/E_s = 0$. This may be assumed as being at B.

If relay and breaker action is correct, both ends of the interconnecting circuit are immediately tripped out, and the systems begin to drift apart as indicated in the swing curve, Figure 5. By the time the interconnection has been reclosed at both ends, terminal voltages will have drifted apart by several degrees so that the impedance "seen" by relays has moved around the impedance circle from original position A toward the line of centers 0–0 and now occupies position C, possibly on another circle representing a different ratio E_r/E_s. Further swing increases the angle δ_{rs} until the respective accelerations of the two systems have been overcome and δ_{rs} has reached maximum value.

As has been pointed out earlier in this paper, the angle (δ_{rs}max) may exceed 90 degrees, and the resulting impedances may fall in the general vicinity of D. Recovery of the system toward normal voltages and angles causes the impedance to retrace path D, C, A and oscillate about the original angle and impedance values at A until the systems finally resume their original relation.

A similar step-by-step analysis of behavior based upon the opposite flow of power, that is *from circuit to bus*, is represented by a similar group of points, E, B, F, G, and E, on the left-hand side of the diagram.

Impedance Referred to Far End of a Nonuniform Circuit

Figure 9, which is the plot of equation 3, has been used in the preceding discussion of conditions as "seen" when "looking into" the circuit from the near end or so-called, but somewhat misnamed, "sending end." To complete the study, it is necessary to investigate at the same time what takes place at the far end or receiving end of the circuit. Figure 10 is the plot of equation 6, which presents the same information in terms of far-end or receiving quantities. In comparing these two Figures 9 and 10, the first thing which attracts attention is the fact that the diagrams are similar in construction except for 180-degree rotation with respect to the axis of the diagram. The rotation corresponds to the change in viewpoint required to "see" the circuit from the opposite end. The dimensions of these two diagrams differ from each other only for *nonuniform* circuits in which $D < \Delta$ is not equal to $A < \alpha$. For uniform symmetrical lines, or for such lines terminated in transformer banks having identical electrical characteristics, it would be sufficient to use Figure 9 for far-end or receiving conditions by making the following changes:

(*a*). Rotate the diagram 180 degrees.

(*b*). Reverse the resistance scales, R for $-R$ and vice versa.

(*c*). Reverse the reactance scales, X for $-X$ and vice versa.

(*d*). Substitute reciprocal values for the ratios E_r/E_s.

(*e*). Substitute conjugate values for the angles δ_{rs}; that is, in place of $\delta_{rs} = 45$ degrees substitute $\delta_{rs} = 315$ degrees, and so forth.

Application of Impedance Circle Diagrams to Long-Line Relaying

The impedance circle diagrams, Figures 9 and 10, can be combined on one chart to give a very complete picture of impedance conditions affecting simultaneous relay performance at the two ends of an interconnecting circuit in the following manner:

1. Cut off each diagram along the straight lines representing the condition $E_r/E_s = D$ in the near-end sending diagram, Figure 9, and the condition $E_s/E_r = A$ in the far-end receiving diagram, Figure 10.

2. Fit the two diagrams together along these two lines and match lines of centers 0–0.

The co-ordinates of the two diagrams are thus offset from each other both horizontally and vertically.

Figure 11 is the result of such combination for the Kansas–Nebraska 154-kv interconnection. Because transformers at the opposite ends of this line are not alike, the A and D constants of the circuit are not equal. Consequently the co-ordinates are skewed slightly, and impedance values scaled across the boundary line L–L are not strictly accurate. In spite of these minor shortcomings, the combined diagrams furnish an excellent basis for relay studies.

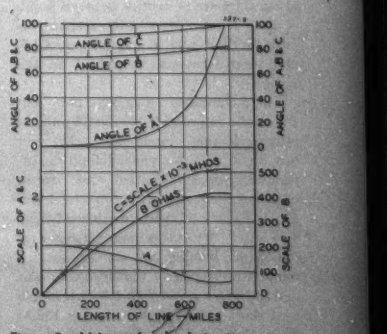
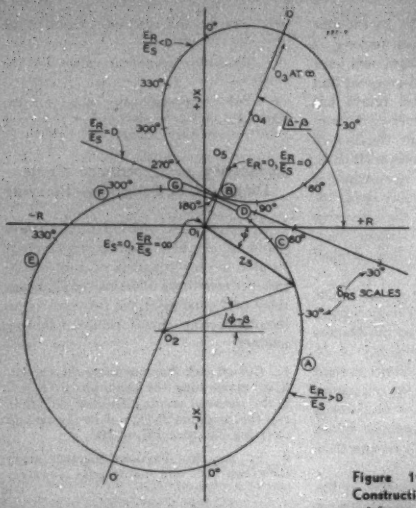


Figure 8. Values of general circuit constants A, B, and C as a function of length for a line having the following constants:

$r = 0.252$ ohm per mile
$x = 0.803$ ohm per mile
$b = 5.22 \times 10^{-6}$ mho per mile


$\frac{E_R}{E_S}$<D
330°
300°
270°
$\frac{E_R}{E_S}$=0
300°
180°
330°
E_S=0, $\frac{E_R}{E_S}$=∞
O_3 AT ∞
O_4
O_5
E_R=0, $\frac{E_R}{E_S}$=0
60°
90°
60°
30°
30°
30°
O_1
O_2
Z_S
$\phi-\beta$
$\Delta-\beta$
+JX
-JX
-R
+R
$\frac{E_R}{E_S}$>D
0°
0°
A
B
C
D
E
F
G
O
O
O

characteristics may be expressed in terms of impedance magnitude and angle on diagrams similar to Figure 9 and Figure 11. If these impedance diagrams are used, it is possible to define completely and clearly the necessary relay requirements to protect and control a long power-transmission circuit or interconnection.

Required Performance of Long-Line Relays

Expressed in the language of these diagrams, relays for long power-transmission lines or for loose-linked interconnections should:

1. Close their trip-circuit contacts instantaneously at both terminals for all impedance values occurring between terminals N and K in areas B and H of Figure 12 caused by either power swings or faults.

2. Not trip at any time for values of circuit impedance corresponding to high-power swings or high kilovolt-ampere transfers in the areas A, A', D, D', or E, E', G, G'.

3. Provide time-delay backup tripping for faults in areas B and H which are beyond the far end of the circuit.

4. Prevent immediate tripping of terminal breakers, for faults in the systems external to the protected circuit, by means of carrier-current blocking principles. There should be no objection to such tripping after proper time delay.

5. Provide instantaneous tripping of terminal breakers for ground faults on the protected circuit by means of carrier-current-controlled directional ground relays.

6. Provide time-delay backup protection independent of carrier-current control for all ground faults.

Limitations of Long-Line Protective Relays

From a very brief study of lines longer than the 270-mile interconnection cited in this paper, it appears that these same principles of protective relaying can be applied to transmission lines of greater length without intermediate switching up to any limit at which synchronism can be maintained between constant voltage systems. This limitation is imposed by the fact that the input-impedance angles $\psi = \tan^{-1} X/R$ for such long lines approach the characteristic impedance angle which is small.

In considering the field of unusually long-distance transmission of power, it appears that but little consideration has yet been given to methods of protecting the lines to differentiate between faults and power swings. It is hoped that this analysis of relay performance requirements will stimulate thought and discussion on this complex subject.

Appendix I. Power-Circle-Diagram Equations 1 and 4

The general $ABCD$ equations for a circuit are

$$E_s = A \cdot E_r + B \cdot I_r \tag{7}$$

$$I_s = C \cdot E_r + D \cdot I_r \tag{8}$$

From equation 7, $I_r = (E_s/B) - (A \cdot E_r/B)$.

Substituting this into equation 8, we have

$$I_s = C \cdot E_r + D \cdot \left(\frac{E_s}{B} - \frac{A \cdot E_r}{B} \right)$$

$$= \frac{D \cdot E_s}{B} + E_r \left(C - \frac{A \cdot D}{B} \right) \tag{9}$$

$$I_s = \frac{D \cdot E_s}{B} + \frac{E_r}{B} \cdot (B \cdot C - A \cdot D)$$

Since $A \cdot D - B \cdot C = 1$

$$I_s = \frac{D \cdot E_s}{B} - \frac{E_r}{B} \tag{10}$$

Using equation 10 and substituting for I_s in

$$P_s = \sqrt{3}\ (\text{conj}\ E_s) \cdot I_s = P \pm jQ$$

$$P_s = \frac{(\text{conj}\ E_s) \cdot D \cdot E_s}{B} - \frac{(\text{conj}\ E_s) \cdot E_r}{B} \tag{11}$$

If δ_{rs} represents the variable angle between terminal bus voltages, this equation may be expressed as follows (writing the circuit constants in polar form):

$$P_s = \frac{E_s^2 \cdot D/\underline{\Delta}}{B/\underline{\beta}} - \frac{E_s \cdot E_r/\underline{\delta_{rs}}}{B/\underline{\beta}} \tag{1}$$

or

$$P_s = \frac{E_s^2 \cdot D}{B}/(\Delta - \beta) - \frac{E_s \cdot E_r}{B}/(\delta_{rs} + \beta) \tag{1}$$

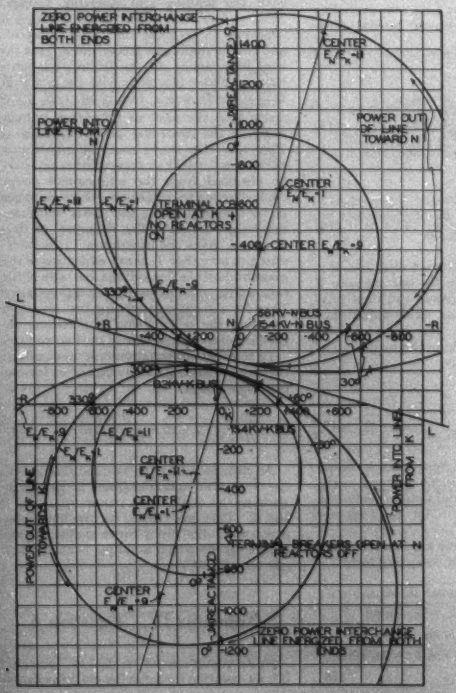
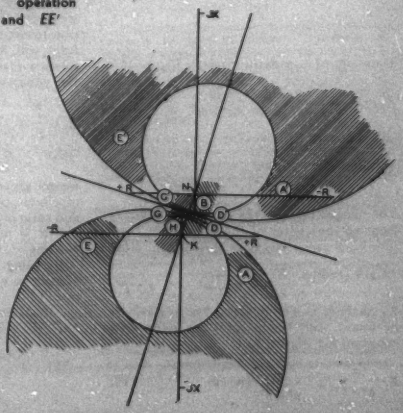

ZERO POWER INTERCHANGE LINE ENERGIZED FROM BOTH ENDS
CENTER
POWER INTO LINE FROM N
POWER OUT OF LINE TOWARD N
TERMINAL BREAKERS OPEN AT N NO REACTORS ON
345 KV-N BUS
154 KV-K BUS
TERMINAL BREAKERS OPEN AT N REACTORS OFF
ZERO POWER INTERCHANGE LINE ENERGIZED FROM BOTH ENDS

Figure 11 (left). Combined sending-end and receiving-end impedance circle diagrams for Kansas–Nebraska 154-kv interconnection including transformers at both ends

Figure 12 (below). Same as Figure 11 but showing areas of fault BH, swing DD' and GG', and normal operation AA' and EE'



Similarly, solving for E_s and I_r from equations 7 and 8, equation 4 for receiving power may be obtained.

$$P_r = \frac{E_s \cdot E_r}{B}\angle(\delta_{rs}-\beta) - \frac{E_r^2 \cdot A}{B}\angle(\beta-\alpha) \qquad (4)$$

In equations 7, 8, 9, and 10, voltages, currents, and circuit constants are on phase-to-neutral basis. In equations 11, 1, and 4 power is total three-phase power with voltages on a phase-to-phase basis, currents are phase currents, and circuit constants are on phase-to-neutral basis.

Appendix II. Basic Impedance Circle Diagram Equation

In order to derive equations 3 and 6, the following review is presented covering the method of inverting a complex quantity of the form:

$$Y_s = a\angle\alpha - b\angle(\delta-\beta) \text{ (see reference 8)} \qquad (12)$$

This equation is an admittance form which can be converted to the impedance form using graphical resolution and some artifices.

A plot of admittance, equation 12, is shown in Figure 13. $a\angle\alpha$ locates the center of the circle, and $b\angle(\delta-\beta)$ is the rotating vector with variable angle δ. Principal points in this figure are labelled 1, 2, and 3.

If the reciprocals of points on this circle are taken and plotted on a convenient scale, another circle will result as shown in Figure 14, which is the locus of the end of the impedance vector Z_s (the reciprocal of Y_s), and points on it are conjugate impedance values from Figure 13. An equation may be derived for Figure 14 by first comparing points along the complex quantity passing through the center of the circle with corresponding points in Figure 13. If Y_{o1} is the distance from the origin to point 1, then, if the values from equation 12 for the distance to the center of the circle and radius of circle are used, $Y_{o1} = a-b$ and $Y_{o2} = a+b$.

The corresponding points in the impedance diagram Figure 14 are

$$Z_{o1} = \frac{1}{a-b}, \quad Z_{o2} = \frac{1}{a+b}$$

Diameter of impedance circle in Figure 14 is

$$Z_{o1} - Z_{o2} = \frac{1}{a-b} - \frac{1}{a+b} = \frac{2b}{a^2-b^2}$$

and radius is

$$R = \frac{\text{diameter}}{2} = \frac{Z_{o1}-Z_{o2}}{2} = \frac{b}{a^2-b^2}$$

The magnitude of the complex quantity locating the center of the impedance circle is

$$(Z_{o2}) + (\text{radius},\ R) = \frac{1}{a+b} + \frac{b}{a^2-b^2} = \frac{a}{a^2-b^2}$$

By analysis and comparison the angles may be found, and hence complete impedance equation for Figure 14 is

$$Z = \frac{a}{a^2-b^2}\angle\alpha - \frac{b}{a^2-b^2}\angle(\phi-\beta) \qquad (13)$$

It is interesting to note how the preceding equation 13 is related to the admittance equation 12. The constants a and b are now divided by (a^2-b^2). Also the conjugate of $\angle\alpha$ and $\angle(\delta-\beta)$ are the angles of the fixed quantity and radius of the circle respectively. But angle δ is not the same as ϕ as discussed later in the following appendix.

Appendix III. Equation 3

The derivation of this impedance equation is based on the following fundamental equations:

$$Z_s = \frac{(\text{conj } E_s)\cdot E_s}{P_s} = \frac{E_s^2}{P_s} \qquad (2)$$

$$P_s = \frac{E_s^2 \cdot D}{B}\angle(\Delta-\beta) - \frac{E_s \cdot E_r}{B}\angle(\delta_{rs}+\beta) \qquad (1)$$

Equation 2 shows the relation between the three-phase power in any part of a circuit, the phase-to-phase voltage of that part of the circuit, and the phase-to-neutral impedance. Equation 1 is derived in Appendix I.

The reciprocal of equation 2 is the admittance form as follows:

$$Y_s = \frac{1}{Z_s} = \frac{P_s}{E_s^2} \qquad (14)$$

Substituting equation 1 into the preceding equation gives the following general equation:

$$Y_s = \frac{1}{Z_s} = \frac{\dfrac{E_s^2 \cdot D}{B}\angle(\Delta-\beta) - \dfrac{E_r \cdot E_s}{B}\angle(\delta_{rs}+\beta)}{E_s^2} \qquad (15)$$

on simplifying

$$Y_s = \frac{1}{Z_s} = \frac{D}{B}\angle(\Delta-\beta) - \frac{E_r}{E_s \cdot B}\angle(\delta_{rs}+\beta) \qquad (16)$$

Since this is an admittance equation, it is not wholly satisfactory for our purpose if we discuss impedance relays and their relation to circuit impedance. This admittance form will, however, be very useful as will be shown later. By taking the reciprocal of this equation, as follows:

$$Z_s = \frac{1}{Y_s} = \frac{1}{\dfrac{D}{B}\angle(\Delta-\beta) - \dfrac{E_r}{E_s \cdot B}\angle(\delta_{rs}+\beta)} \qquad (17)$$

we get an equation for impedance in terms of circuit constants, circuit voltage angle, and ratio of receiving and sending voltages, but it is not in a form for conveniently plotting.

By going through some algebra, equation 17 may be written in the following form:

$$Z_s = \frac{(b_1a_1+b_1a_2)+(b_2\sin\delta_{rs}-b_1\cos\delta_{rs})}{1+|A|^2-2a_1\cos\delta_{rs}-2a_2\sin\delta_{rs}} + j\frac{(b_2a_1-b_1a_2)+(b_1\sin\delta_{rs}-b_2\cos\delta_{rs})}{1+|A|^2-2a_1\cos\delta_{rs}-2a_2\sin\delta_{rs}} \qquad (18)$$

which also is not conveniently usable because of the large amount of arithmetical work required to plot the diagram representing it.

Instead of directly inverting equation 16, inverting an admittance equation to an impedance form as in Appendix II simplifies greatly the amount of work required and is a method commonly used. Admittance equation 16 was converted to the following impedance equation in this way:

$$Z_s = \frac{D\cdot B}{D^2-\left(\dfrac{E_r}{E_s}\right)^2}\angle(\Delta-\beta) - \frac{B\cdot\left(\dfrac{E_r}{E_s}\right)}{D^2-\left(\dfrac{E_r}{E_s}\right)^2}\angle(\phi-\beta) \qquad (3)$$

This equation for impedance includes the general circuit constants, angles of these constants, ratio of the receiving and sending voltages, and the angle ϕ. The diagram for this equation is Figure 9 discussed in the text of the paper.

Again referring to equation 16, if $E_s = E_r$, then this equation takes the following simple form:

$$Y_s = \frac{D}{B}\angle(\Delta-\beta) - \frac{1}{B}\angle(\delta_{rs}+\beta) \qquad (19)$$

which is the sending-end power, equation 1, with the sending and receiving voltages equal to one volt. Thus the admittance is expressed in terms of the circuit constants and circuit angle, and it does not include the load impedance. On analyzing this equation, we find it is a circle with the center at $D/B\angle(\Delta-\beta)$ and a radius of $1/B$. The angle δ_{rs} is the same as the circuit voltage angle in the preceding power equation 1. This operation shows that the admittance value of a network or transmission line may be obtained from the sending-end power circle diagram for conditions where E_r equals E_s by simply dividing the power and reactive values by E_s^2. The reciprocal of this, of course, gives the impedance. It is interesting to note that Y_s is not a function of the magnitude of the line voltage, but only of the ratio of the sending and receiving voltages. Thus for a given transmission line, equation 19 gives the sending-end admittance, regardless of the magnitude of the line voltage.

In reference to equation 3, if E_r equal E_s, then the following simple equation for impedance results:

$$Z_s = \frac{D\cdot B}{D^2-1}\angle(\Delta-\beta) - \frac{B}{D^2-1}\angle(\phi-\beta) \qquad (20)$$

As mentioned in the text of this paper, the angle ϕ in equations 3 and 20 is not the same as the angle δ_{rs} in power equations 1 and 4. They are related for the particular problem studied by a curve similar to the Figure 15 for which a simple equation has not been found.

Appendix IV. Equation 6

In a manner similar to that in Appendix III, an equation for receiving-end impedance

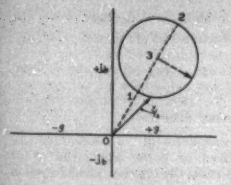


Figure 13. Admittance circle—Y_s

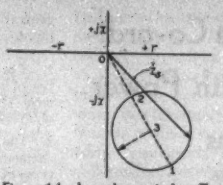


Figure 14. Impedance circle—Z_r derived from Figure 13

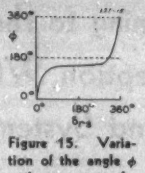


Figure 15. Variation of the angle ϕ with respect to the angle δ_{rs}

may be derived using the following fundamental formula for impedance:

$$Z_r = \frac{(\text{conj } \boldsymbol{E}_r)\cdot \boldsymbol{E}_r}{P_r} = \frac{E_r^2}{P_r} \qquad (5)$$

and the following equation for receiving-end power derived in Appendix I:

$$P_r = \frac{E_s \cdot E_r}{B}\angle(\delta_{rs}-\beta) - \frac{E_r^2 \cdot A}{B}\angle(\beta-\alpha) \qquad (4)$$

we obtain the following equation for receiving-end impedance:

$$Z_r = \frac{B\cdot\left(\frac{E_s}{E_r}\right)}{A^2-\left(\frac{E_s}{E_r}\right)^2}\angle(\phi+\beta) - \frac{A\cdot B}{A^2-\left(\frac{E_s}{E_r}\right)^2}\angle(\beta-\alpha) \qquad (6)$$

This equation may be plotted in the same manner used to plot equation 3 for sending-end impedance circle. Again if $E_r = E_s$, then the above reduces to

$$Z_r = \frac{B}{A^2-1}\angle(\phi+\beta) - \frac{A\cdot B}{A^2-1}\angle(\beta-\alpha) \qquad (21)$$

Similarly to equation 16

$$Y_r = \frac{E_s}{E_r\cdot B}\angle(\delta_{rs}-\beta) - \frac{A}{B}\cdot\angle(\beta-\alpha) \qquad (22)$$

Appendix V. Plotting Impedance Circle Diagrams

Impedance circle diagram in Figure 9 was plotted by first calculating the vector which locates the center of the circles and the radii of the circles, using the following equation for impedance:

$$Z_r = \frac{D\cdot B}{D^2-\left(\frac{E_r}{E_s}\right)^2}\angle(\Delta-\beta) - \frac{B\cdot\left(\frac{E_r}{E_s}\right)}{D^2-\left(\frac{E_r}{E_s}\right)^2}\angle(\phi-\beta) \qquad (3)$$

Since the angle ϕ does not bear a simple relation to δ_{rs}, the degree points on the diagrams corresponding to values of δ_{rs} were obtained by taking the reciprocal of the admittance quantity obtained from equation 16 after ratios of approximate system voltages and circuit constants had been substituted into it.

Similarly equation 6 was plotted and degree points for δ_{rs} were located by using equation 22 to find the admittance for a given value of δ_{rs}.

Appendix VI. General Circuit Constants

General circuit constants used in the impedance, admittance, and power equations for the Kansas–Nebraska 154-kv interconnection including transformers are

$$A = A\angle\alpha = a_1 + jb_2 = 0.824\angle 3.25°$$

$$B = B\angle\beta = b_1 + jb_2 = 282\angle 77.3° \text{ ohms}$$

$$C = C\angle\underline{c} = c_1 + jc_2 = 1.337\times10^{-6}\angle 90.9° \text{ mhos}$$

$$D = D\angle\Delta = d_1 + jd_2 = 0.769\angle 3.56°$$

Appendix VII. Auxiliary Formulas

Using the general $ABCD$ circuit equations 7 and 8, Appendix I, auxiliary formulas were derived for calculating limiting circuit impedances.

Sending-end impedance as function of load impedance is

$$Z_s = \frac{A\cdot Z_r + B}{C\cdot Z_r + D} \qquad (23)$$

Assume short circuit at R end; that is, $E_r = 0$, then

$$Z_s = \frac{B}{D} \qquad (24)$$

with the circuit open at R end, that is, $I_r = 0$, then

$$Z_s = \frac{A}{C} \qquad (25)$$

The same general equations 7 and 8 and same reference angles being used, the receiving impedance Z_r in terms of the sending impedance Z_s is

$$Z_r = \frac{D\cdot Z_s - B}{-C\cdot Z_s + A} \qquad (26)$$

Assume short circuit at S end; that is $E_s = 0$, then

$$Z_r = -\frac{B}{A} \qquad (27)$$

With S end open; that is $I_s = 0$, then

$$Z_r = -\frac{D}{C} \qquad (28)$$

Appendix VIII. Nomenclature

Z_s—Equivalent or apparent phase-to-neutral impedance in ohms looking into the sending end assumed for purpose of establishing a convention for signs and reference angles during calculations.

Z_r—Equivalent or apparent phase-to-neutral impedance in ohms at receiving end.

Z—Impedance expressed in vector form.

Y_s, Y_r—Equivalent or apparent phase-to-neutral admittances in mhos.

ψ—Tan$^{-1}\frac{X}{R}$ of impedance Z.

ϕ—The angle of the variable in equations 3 and 6.

δ_{rs}—Angle in degrees by which the sending-end voltage leads the receiving voltage.

A, B, C, D—General circuit constants expressed in vector form.

P_s—Sending-end power expressed as a vector $= P_s = jQ_s = P_s\angle\theta$.

P_r—Receiving-end power expressed as a vector $= P_r = jQ_r = P_r\angle\theta$.

θ—Power-factor angle of sending or receiving power.

E_s—Phase-to-phase volts at sending end. Phase-to-neutral volts in equations 7, 8, 9, and 10.

E_r—Phase-to-phase volts at receiving end. Phase-to-neutral volts in equations 7, 8, 9, and 10.

$\boldsymbol{E}_s$, $\boldsymbol{E}_r$—Vector forms of E_s and E_r, respectively

(conj $\boldsymbol{E}_s$), (conj $\boldsymbol{E}_r$)—Conjugate vector forms of $\boldsymbol{E}_s$ and $\boldsymbol{E}_r$, respectively, that is, with angular rotation measured in *opposite* direction from reference line compared to direction of measurement for $\boldsymbol{E}_s$ and $\boldsymbol{E}_r$.

(conj $\boldsymbol{E}_r$)$\cdot\boldsymbol{E}_r = E_r^2$.

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Measurements Pertaining to the Co-ordination of Radio Reception With Power Apparatus and Systems

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I. Introduction

EXPERIENCE has shown that electric-power apparatus and circuits may, under certain circumstances, influence radio reception. Groups* representing electric-apparatus manufacturers, power companies, radio-apparatus manufacturers and service have been co-operating for several years on the control of this influence. Reports by these groups have summarized progress as this work proceeded. Standard measurement equipments and methods have been established. Papers have been presented also covering various aspects of the general problem. This paper gives the results of practical experience with standard equipments and methods for the measurement of radio influence factors. The various elements in the chain between measured characteristics of the power apparatus and the noise measured in the radio set are analyzed. Quantitative values for the various factors involved in average cases are given.

Problems attendant to interference control by general consent are approached with the attitude that we must have the services of both power and radio and that each must adjust itself to live with the other on the practical basis of general usefulness and reasonable economy. Power service groups have made progress in controlling interference phenomena in their circuits. In the radio field improved reception has been realized. Each group is continuing its endeavors to improve its own facilities. They are also working together co-operatively to understand the problems involved and by joint effort to arrive at the most satisfactory over-all solution.

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* American Standards Association committee on radio electrical co-ordination; Joint Co-ordination Committee on Radio Reception of Edison Electric Institute, National Electrical Manufacturers Association and Radio Manufacturers Association; National Electrical Manufacturers Association committee on co-ordination of acoustic relations of power and communication apparatus and systems.

II. General Situation

The general scope of the co-ordination problem ranges widely through many branches of the power and radio fields, and accordingly a comprehensive plan of attack might appear difficult. However, the general situation has naturally divided itself into four parts, each one of which falls automatically into the hands of a technical group whose regular interests prompt ready response to the attendant problems.

These divisions are as follows:

1. Power circuit generation, transmission and distribution and power equipment, including utilities, industrial and domestic classifications. These constitute the generating sources of the influence phenomena and the circuits which transmit them to points of exposure to the radio circuits.

2. The radio receivers and circuits which may be susceptible to the influence of the power apparatus.

3. Magnetic or electrostatic coupling between power circuits of 1 and radio circuits of 2.

4. Measuring instruments which are suitable for the quantitative evaluation of currents and voltages associated with interference or interference conditions.

The technical problems of the first division fall naturally to the electric-power group; those of the second to the radio group; those of the third to co-operative effort between the power and radio groups, and the fourth or instrument division to instrument technicians of both groups.

III. The Immediate Problem

Within this situation, as already outlined, the immediate practical problem of increasing control and reducing interference is that of recognizing the factors involved, determining their significant relations and evaluating them quantitatively. Experience seems to indicate that the general problem is concerned with the following factors and particular problems:

1. The design, construction, and calibration of instruments suitable for the measurement of the electrical characteristics of radio-influence phenomena.

2. The measurement of radio-influence characteristics of power apparatus of all types to indicate the relative influence possibilities when placed in service.

3. The measurement of radio-influence voltage on power lines to establish a relation between the value existing on the line and the measured characteristics of the apparatus connected to it as found in item 2.

4. The measurement of radio-influence voltage under the power line to establish the relation between the radio-influence voltage at some standard position adjacent to the line but not connected to it and the radio-influence voltage on the line as measured in item 3.

5. The measurement of radio-noise voltage on the receiver antenna to determine the relation between its value and the radio-influence voltage measured at the standard position under the power line in item 4.

6. The measurement of the susceptibility of the radio receivers and antennas to extraneous influences.

7. The determination of limiting values for the ratio of signal to noise for good reception.

8. The determination of limiting program signal strengths on which to base a criterion of good reception.

9. The design of suitable equipment or arrangements for the reduction of radio-noise phenomena where prevailing levels are above those consistent with good reception.

This paper will take up these factors and problems and endeavor to present pertinent data and show the present status of each.

IV. Radio-Noise Meters and Calibrations

Satisfactory instruments for the measurement of radio-interference phenomena have certain unusual requirements:

1. They must measure a standardized quantity significant to the noise output of broadcast receivers.

2. They must be extremely sensitive. Voltages as low as a few microvolts (millionths of a volt) must be measured.

3. They must cover a wide range of wave shapes and equivalent frequencies. Radio-interference phenomena vary from single-polarity impulses or damped oscillations of widely different recurrent times to continuous waves of constant frequency. Amplitudes also vary quite irregularly.

Progress in instrument design and in methods of operation have been made, and these developments have been reported

as fast as experience justified.[1-4] For some time now, two makes of radio-noise meters have been available commercially, and considerable experience has accumulated as to their operational performance. To summarize this experience briefly, some results on sine-wave calibration, square-wave calibration, and noise tests on several devices are reported here.

As regards instrument calibrations, both instruments are supplied with a self-contained calibrating signal source which utilizes the electron shot noise of a saturated diode as the calibrating voltage. Operating instructions on calibration call for the following:

1. Tune the noise meter to the desired frequency.
2. Adjust the calibration circuit to the reference point on the noise-meter scale.
3. Adjust the noise-meter amplification until the meter reads the scale value on the calibration curve for the frequency selected.

This calibration procedure has been followed closely, and, in addition, at frequent intervals and before each set of important noise measurements, a check calibration against a signal generator has been made, following the settings called for on the internal calibrator. Many of these complete calibrations have been on both instruments, and rather complete data are, therefore, now available. The general trend of these data is represented by the specimen curves of Figure 1. These were all made at 1,000 kilocycles.

These data show that the accuracy provided by the use of the internal calibrator alone as recommended will be within ±20 per cent for the microvolt range of 10 to 100. For the higher range 100 to 100,000 microvolts, the deviation occasionally goes above ±50 per cent, particularly at the upper end of the measurement range. For any one instrument calibration a high or low trend persisting throughout the measurement range is quite evident. This trend results in lower accuracy for the higher magnitudes of microvolt levels.

Table I. Comparison of Noise Meters on Square Waves

Square-Wave Reference Setting	Noise-Meter Measurements		Per Cent Deviation Based on B
	Type A	Type B	
0.14	58	45	+29
0.22	105	75	+40
0.38	210	150	+40
0.53	310	220	+41
0.65	370	290	+34
0.78	480	350	+37
0.90	580	410	+41
1.05	670	500	+34
		Average	+37

Each instrument has a tendency to read high or low on an average basis, and each one may vary from one calibration to another. This calibration experience is presented as representative of that obtained in a laboratory where operators are familiar technically with the details of such measurements.

If greater accuracy is desired, the radio-noise meter may be used by connecting it to the circuit in which the noise is to be measured and noting the reading. It is then connected to the signal generator and the output adjusted until the same reading is obtained on the radio-noise meter. The output of the signal generator then gives the radio-influence voltage in microvolts. Such a method of measurement is slower but results in accuracies within eight per cent.

The preceding comparison has been made on the basis of a sine wave of radio frequency produced by a signal generator. As the radio-influence voltage measured on electric apparatus is not usually sinusoidal in character but may consist of a very irregular frequency spectrum, it is desirable to have some idea of the behavior of the instruments on other types of waves. Since square-wave signal generators are available, it was decided to compare the performance of the radio-noise meters on this type of wave. An interesting specimen measurement wherein the two noise-meter types were compared for response is summarized in Table I.

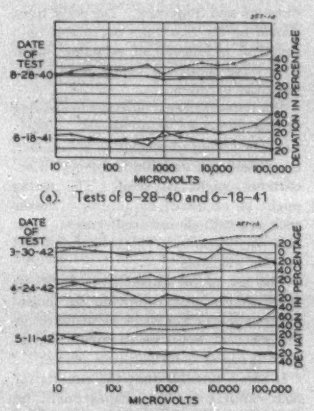

Figure 1. Radio-noise-meter calibrations

Solid lines all apply to an instrument of one make. Dotted lines all apply to an instrument of another make

These measurements were made with the two meters connected in parallel on the square-wave generator following calibrations of each instrument on a sine-wave signal generator at 1,000 kilocycles. A definite difference between the two instruments is indicated by these data over a wide range of voltage magnitudes. Type *A* reads on an average 37 per cent higher than type *B*. The obvious conclusion is that setting on the internal calibrator supplemented by sine-wave calibration may nevertheless result in considerable differences in readings for two instruments on different wave shapes. In view of the wide range of wave shapes and equivalent frequencies common to radio-noise phenomena, this circumstance shows a definite need for further work to reduce these differences.

As regards comparisons between the two types of meters on measurement of radio-influence voltage of power apparatus, both high and low voltage, data of Table II are interesting. These comparative tests were made following a sine-wave calibration on the signal generator. Measurements were made in each case with the two instruments connected in parallel.

As these data are backed up by sine-wave calibrations and were obtained with the two types of instruments connected in parallel and measured at the same time, they show directly a rather widely different instrument response. This difference in per cent ranges up to 35 per cent and persists over a wide range of noise-voltage magnitudes without any evident trend as to magnitude.

Both types of instruments used in these tests are arranged by their designers to be

Table II. Comparison of Noise Meters on Power Apparatus

Test No.	Test Voltage (60 Cycles) Kilovolts	Radio-Influence Voltage (Microvolts) Instruments		Per Cent Deviation Reading Type B Instrument
		Type A	Type B	
1 Insulator	10	480	450	+ 7.0
	16	2,600	2,600	0
	22	4,200	4,900	−14.0
	28	5,200	6,000	−13.0
2 Insulator	10	2,100	1,900	+10.0
	16	7,900	8,200	− 3.0
	22	13,000	16,000	−19.0
	28	20,000	23,000	−13.0
3 Small gap	14	23,000	17,000	+35.0
4 1st small motor	0.115	290	250	+16.0
	0.115	1,600	1,200	+33.0
5 2nd small motor	0.115	1,300	1,600	−19.0
	0.115	1,900	1,750	+ 8.0

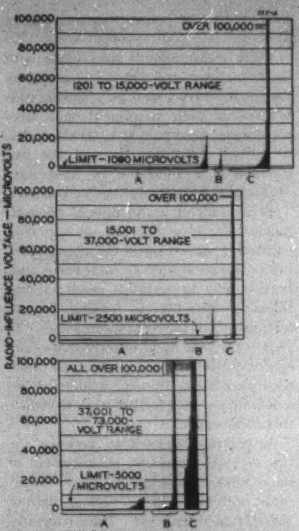

Figure 2. Summary charts of radio-influence voltage data on high-voltage apparatus

For 1,201- to 15,000-volt range each vertical line or dot represents five tests. For all other ranges each vertical line or dot represents one test

A—New apparatus
B—In service without complaints of radio noise
C—Removed because of radio noise and complaints

in general accord with the specifications.[5] Some investigational work has been directed toward the evaluation of instrument characteristics, such as detector-circuit time constants, to ascertain how variations in these might contribute toward measurement differences. To date this has not resulted in improved measurement accuracies.

Consideration of the calibration problem usually proceeds along the lines of specifying instrument-design details or specifying certain calibration waves. The present specifications cover only such over-all design features as seemed necessary to the duplication of radio-receiver characteristics pertinent to noise levels and the incorporation of good instrumentation qualities. Specific details of circuits were not recommended and to the designer was left the freedom of selecting these and improving them when progress permitted. This attitude insures a situation in which advances in design are stimulated.

However, from the above data which are believed to be generally representative, it is obvious that further specifications are necessary. In view of the indicated importance of wave shape, it is desirable that steps be taken toward the specification of calibrating waves of representative shape and equivalent frequency. This has been suggested by one of the authors,[7] and proposals along similar lines have been made by others.

The sine wave now occupies an important place in calibration, is readily obtained, and should be retained. To it might be added a square wave of variable duration and frequency. The wave front should be the maximum obtainable on a practical technical and economic basis. This wave should be available in either polarities to ground.

For investigational purposes in arriving at the necessary wave shapes, a high-frequency damped oscillation of constant decrement and variable frequency of occurrence might be tried. The waves might be examined by recording means such as a cathode-ray oscillograph. Suitable oscillographs of high-writing speed are now available.[8,9]

The use of recommended calibrating-wave shapes would provide for noise-meter calibration or check immediately at the place of noise measurement, or at least at one or more reference places.

It seems possible that the circuits for such calibrating-wave shapes might be standardized in sufficient detail (even to the length of leads, and so forth), so that the wave shapes would be very closely alike. Thus a certain degree of standardization could be accomplished as to wave shape while noise-meter design problems are left entirely in the hands of the instrument designers where they are handled most capably.

To use the radio-noise meter for measurement of radio-influence characteristics of apparatus, it is necessary in order to get comparable results to standardize on setup for making tests. A general recommendation for the making of such tests is given in National Electrical Manufacturers Association publication 107.[4] More specific test codes for particular types of apparatus are given in the NEMA publication for that type of apparatus.

V. Relation of Radio-Influence Voltages of Apparatus to Radio-Receiver Noise

Two methods have been used whereby the radio-influence voltage measured on power apparatus at the factory may be interpreted as having quantitative significance in terms of radio-receiver noise in an average case. In one we analyze the measurements made on new apparatus in the factory and the experience in the field with this apparatus to arrive at a reasonable limit. In the other we consider all the factors given in items 2 through 8 of section III of this paper to obtain values for the following:

1. The radio-influence voltage measured on the apparatus under standardized conditions (apparatus *RIV*).
2. The radio-influence voltage measured on a power line to which this apparatus is connected (line *RIV*).
3. The radio-influence voltage measured on or referred to a one-meter antenna at a standard position under this line (under line *RIV*).
4. The radio-noise voltage measured on an antenna in proximity to this power line and referred to a one-meter antenna (antenna *RNV*).
5. The signal strength of the radio program being received.
6. The signal to noise ratio in the receiving set.
7. The susceptibility of the receiver and antenna system.

1. Radio-Influence Voltage (*RIV*) of Apparatus

For several years we have been collecting measured radio-influence voltage values on a wide range of types of power

Table III. Limits of Radio-Influence Voltage for High-Voltage Apparatus

Circuit Voltage Ratings (Range in Volts)	Insulation Classes (Kilovolts)	Limits of Radio-Influence Voltage (Microvolts)
1,201–15,000	1.2–2.5–5.0–7.5/8.7–15	1,000
15,001–37,000	23/25–34.5	2,500
37,001–73,000	46–69	5,000
73,001–145,000	92–115–138	10,000

1*a*. No limits are included for equipment at circuit voltage ratings above 145,000 volts because of present lack of data above this voltage class.

1*b*. These values do not apply to insulators, as an independent set of values has already been established for them by NEMA, or to motors and generators or thermionic devices, such as rectifiers and inverters.

1*c*. For switchgear assemblies there are not sufficient radio-influence voltage data on which to base a limit.

1*d*. For transformers the limits are based on insulation class only.

2. The radio-influence voltage limits given in this table apply to new apparatus tested in the factory in accordance with the report of the Joint Coordination Committee on Radio Reception of EEI, NEMA, and RMA, entitled "Methods of Measuring Radio Noise" (NEMA publication 107) 1940 and the apparatus test codes and test voltages for each type of apparatus, as approved by NEMA.

3. If apparatus of any given insulation class is used on a circuit of higher-circuit voltage rating, the radio-influence limit and the test voltage for the apparatus shall be that corresponding to its insulation class and not to the insulation class of the circuit on which it is used.

4. For special apparatus having more than one rating the radio-influence limit and test voltage corresponding to the highest rating shall apply.

Table IV. Comparison of Apparatus to On-Line Radio-Influence Voltages

Test Voltage (Kilovolts)	Measured Radio-Influence Voltage on Apparatus (Microvolts)	Measured Radio-Influence Voltage (On-Line) At Apparatus Microvolts	Ratio	At End of Line (2 Miles) Microvolts	Ratio
20	14,000	9,400	1.5	2,600	5.4

apparatus and circuit voltages. These have been classified in three groups, that is, new apparatus, apparatus in service with no complaints, and apparatus removed because of radio noise and radio-noise complaints. These data have been plotted on a summary chart classified into three voltage ranges, and this chart is shown in Figure 2. In the 1,201–15,000-volt range some 950 individual tests are summarized; in the 15,001–37,000-volt range, 130 tests, and in the 37,001–73,000-volt range, 94 tests. Radio-influence voltages ranging from a few microvolts to 100,000 and above are shown.

From a study of such data it is possible to arrive at recommended levels for the limiting value of radio-influence voltage of apparatus. This has been done, and the recommended levels are shown on the curves and are also given in Table III. Such an approach to the question of limiting values is a direct one. It depends upon accumulating sufficient field experience with apparatus to obtain statistical data on which a conclusion may be reached. As time goes on and more data are accumulated, these can be used to confirm the original conclusions or to suggest desirable modifications of them.

Another approach to the problem begins with the values on apparatus and proceeds through the several steps already outlined, such as radio-influence voltage on the power line, under the line, and on the antenna, and signal strength and signal to noise ratio. This approach requires the establishment of representative values for each of these quantities and then combines them all together to arrive at an over-all ratio. The ratio can then be used to interpret radio-influence voltage of apparatus in terms of the quality of radio reception. This method will now be outlined.

2. Ratio of Apparatus *RIV* to On-Line *RIV*

Having the *RIV* of a given piece of apparatus when measured with the standard factory setup, we must be able to form an estimate of the resulting *RIV* when this apparatus is connected to a representative power line. The factory tests are made with 600 ohms across the apparatus, which resistance is intended to simulate line-surge impedance. However, a wide range of impedance will always be met with on power circuits. It is, therefore, necessary to resort to practical measurements wherein factory tests are followed by connection of the apparatus to line, and corresponding line radio-influence voltage measurements are taken. One such test is summarized in Table IV.

This test made on a two-mile test line believed to be representative showed a ratio of 1.5 to 1 between apparatus *RIV* and on-line *RIV*. It also indicated an attenuation of 50 per cent radio-influence voltage per mile, which figure agrees closely with a series of tests made with sine waves on the same line.

3. Ratio of On-Line *RIV* to Under-Line *RIV*

Since in measurements in the field it is not possible to make measurements of the on-line *RIV* except in special cases, the common procedure has been to make measurements under the line. Such measurements of under-line *RIV* can be correlated with the on-line *RIV* by selection of a suitable place under the line which can be used as a field-strength reference point. The field-strength reference position which has been chosen as most significant and practical is one immediately under the line and midway between the poles. The *RIV* measured on an antenna of one-meter effective height placed at this reference point is designated in this paper as the under-line *RIV*. Since this measurement is referred to a one-meter antenna, it gives the same numerical value as the field intensity of the noise phenomenon at the reference point which has been used by some investigators. Corresponding measurements made on the line and under the line under specified conditions will provide a ratio which can be used later to evaluate under-line noise field strengths. To provide such a ratio, a series of measurements was made on the experimental line previously mentioned using sine-wave line-voltage excitation at 1,000,000 cycles. This line averaged 28 feet in height and was terminated to ground through a surge impedance of 600 ohms, and measurements were made at several points along the line as indicated in Table V.

Table V. Comparison of On-Line to Under-Line Radio-Influence Voltages

Test Point Along the Line in Feet	On-Line *RIV* (Microvolts)	Under-Line *RIV* (Microvolts)	Ratio On Line Under Line
0	75,000	950	79
900	58,000	1,400	42
1,400	53,000	1,040	51
5,400	28,000	420	67
8,500	24,000	800	30
10,000	16,500	270	61
		Average	55

The on-line to under-line ratios range from 30 to 79 with an average of 55. Two factors at least are known to have contributed to this variation. These were uncertainties of electrical contact on the conductor for the on-line measurements and variations in line height. The test results of Table V, however, represent an average field situation and may, therefore, be used to provide the quantitative ratio necessary to this particular step between apparatus *RIV* and radio-receiver noise.

4. Ratio of Under-Line *RIV* to Antenna *RNV*

Next in order, it is necessary to establish a ratio between under-line and antenna voltages. If the antenna voltage is expressed in terms of a one-meter antenna, as previously described for the under-line measurement, such a significant ratio will result. A series of tests made in Canada by the radio division of the Department of Transport and directed by H. O. Merriman include a large number of field

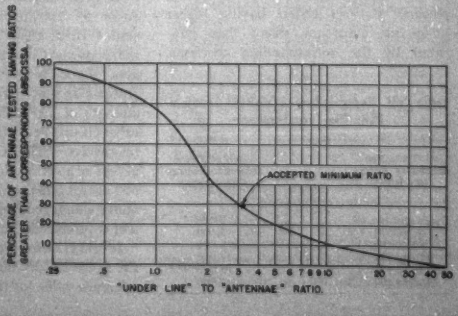

Figure 3. Under-line - to - antenna radio - influence-voltage ratios

Table VI. Test Voltages for Radio-Influence Voltage Measurements

I	II	III	Voltage Rating of Apparatus Normally Used				
			Distribution Cutouts		Lightning Arresters		
Circuit Voltage (Line-to Neutral/ Line-to-Line) (Volts)	Radio-Influence Test Voltage (Volts)	ASA Transformer Insulation Class (Kv)	IV Grounded (Kv)	V Ungrounded (Kv)	VI Grounded (Kv)	VII Ungrounded (Kv)	Switchgear VIII (Kv)
1,440/2,500	1,580	2.5	2.5	2.5	3	3	2.5*
2,500/4,330	2,750	5.0	2.5*	5.0	3*	6	5.0
2,880/5,000	3,160	5.0	5.0*	5.0	6	6	5.0*
4,160/7,200	4,570	8.7	7.5	7.5	6	9	7.5*
5,000/8,660	5,500	8.7	7.5	15.0	6*	9	15.0
7,200/12,470	7,960	15.0	7.5*	15.0	9*	15	15.0
7,960/13,800	8,760	15.0	13.0	15.0	12*	15	15.0
8,650/15,000	9,500	15.0	15.0*	15.0	15*	20	15.0*
13,300/23,000	14,600	23.0			20*	25*	23.0*
19,990/34,500	21,900	34.5			30*	37*	34.5*
26,500/46,000	29,300	46.0			40*	50*	46.0*
39,500/69,000	43,900	69.0			60*	73*	69.0*
53,000/92,000	58,500	92.0			78*	97	115.0
66,500/115,000	73,100	115.0			97	121	115.0*
80,000/138,000	87,700	138.0			121*	145	138.0*
93,000/161,000	102,400	161.0			145*	169	161.0*
113,000/196,000	124,600	196.0			169*	205*	230.0
132,500/230,000	146,200	230.0			195*	242	230.0*
165,500/287,500	182,000	287.5			242*	302*	287.5*

* For the apparatus of columns IV through VIII an asterisk is placed on the line which gives the test voltage (column II) for each apparatus rating.

For transformers, test voltages shall be 110 per cent of the maximum rated line-to-neutral voltage but shall not exceed the maximum values (in column II) corresponding to the insulation class of the transformer of column III.

measurements bearing on this ratio. We are indebted to Mr. Merriman for permission to use these results. Measurements were obtained on 35 antennas ranging in effective heights from 0.2 to 9 meters and located from 20 to 4,500 feet from power lines. Line voltages ranged from 10 to 220 kv. It should be understood that the tests were conducted on outdoor antennas representing a selected group of installations in which radio interference from power lines was reported to be particularly troublesome. Under-line-to-antenna voltage ratios derived from these measurements ranged from 0.25 to 50. The higher this ratio the lower the field from the power line picked up by the receiver antenna and the better the antenna system for good reception. These values are plotted on Figure 3 against percentage of antennas tested as ordinate. This ordinate percentage gives the proportion of receiver stations tested having higher under-line-to-antenna ratios than indicated by the corresponding abscissas.

Table VII. Radio-Influence Voltage Limits o Plain Pin-Type Insulators

60-Cycle Dry Flashover Rating (Kv Rms)	Limit of Radio-Influence Voltage (Microvolts)
Up to and inc. 50	2,500
51 to 79	5,500
80 to 109	8,000
110 to 124	12,000
125 to 149	16,000
150 to 200	26,000

Since this investigation was made mainly on "interference-affected" situations, the curve shows only 30 per cent of the antennas had a ratio higher than 3.2. The investigators estimated that, when all receivers were considered, approximately 90 per cent of them would have ratios higher than 3.2. In accordance with these tests, Canadian Practice[10] sets a value of 3.2 for the minimum permissible under-line-to-antenna ratio. This means that ratios less than this for line-to-antenna couplings do not measure up to the performance that reasonably may be required for good reception.

5. Signal Strength of Radio Program

The required signal strength of the radio program for good reception has been estimated by various engineers to range from 10,000 microvolts per meter in large cities to 100 microvolts for sparsely settled rural areas. The Federal Communications Commission recognizes the area for good reception of certain types of stations as that covered by a signal field strength of 500 microvolts and for some other classes field strengths as low as 100 microvolts. The Canadian regulations accept a level of signal field strength of 500 microvolts per meter as a lower limit above which good reception is practically and economically achievable.

It seems, therefore, reasonable to use the figure of 500 microvolts per meter as reference value for this study.

6. Signal-to-Noise Ratio

Several series of listener tests utilizing a range of types of radio noise at various signal strengths and noise levels have indicated that a signal-to-noise ratio of 32 to 1 is an average ratio for use as a criterion of good reception. This ratio is accepted in the Canadian regulations.[11]

A ratio of 40 decibels has been suggested by International Electrotechnical Commission as a suitable signal-to-noise value indicating, however, at the same time, that values higher than 30 decibels have not been achieved in practice. Also, the FCC protects clear channel stations with a signal-to-noise ratio of 20 decibels. The test ratio of 32 to 1 (30 decibels), therefore, seems appropriate.

7. Apparatus Limits Derived From These Ratios

Having discussed the several significant ratios and values, we may now use them to arrive at a reasonable value for the radio-influence voltage of apparatus. If the signal strength of 500 microvolts per meter at the radio receiver is divided by the signal-to-noise ratio of 32 to 1, an antenna radio-noise voltage of 15.6 microvolts is obtained. Using this value with the under-line-to-antenna ratio of 3.2 gives a value of 15.6 times 3.2 equal to 50 microvolts per meter, which is, therefore, an upper limit of noise field intensity at the reference position under the line. This value can now be used with the other ratios to obtain an apparatus limit. For instance, on the 28-foot line previously referred to, with an apparatus-to-on-line ratio of 1.5 and an on-line-to-under-line ratio of 55, the apparatus limit for radio-influence voltage will be 50 times 1.5 times 55 equal to 4,100 microvolts; also for a 35-foot line correcting the 55 ratio proportional to line height now becomes 70 to 1 and gives an apparatus limit for radio-influence voltage of 50 times 1.5 times 70 equal to 5,300 microvolts.

These figures have direct significance when compared with the apparatus limits based on direct experience with factory-measured values as described in section V—1 of this paper and given in Table III.

Table VIII. Radio-Influence Voltage Limits for "Radio-Freed" Pin-Type Insulators

60-Cycle Dry Flashover Rating (Kv Rms)	Limit of Radio-Influence Voltage (Microvolts)
Up to and inc. 50	50
51 to 79	50
80 to 109	100
110 to 124	100
125 to 149	200
150 to 200	200

The greater part of the field data and experimental investigation represented in this analysis are derived from lines of about 66-kv construction. The limit of 5,000 microvolts for this circuit voltage of Table III is between the level for 28-foot- and 35-foot-high lines. It is apparent, therefore, that the limits reached through both approaches are consistent. On lower-voltage lines the apparatus limits of 2,500 and 1,000 microvolts appear to have the necessary margin of safety consistent with their frequent location closer to radio receivers. Also, the higher-voltage range at 10,000 microvolts should be acceptable, because distances to receivers are greater, and because up to this time interference experience has not been sufficient to indicate any practical necessity of a lower limit.

The problem of practical limits for factory tests of radio-influence voltage on apparatus has now been considered from two standpoints, first that of direct experience with factory measurements on apparatus, and second that of experimental determination of significant coupling ratios between apparatus and receiver set. The limits arrived at from these two standpoints are in good agreement.

The values given in Table III have been adopted as limits by many NEMA sections for high-voltage apparatus.

VI. Radio-Influence Test Voltages for Apparatus

Radio-influence voltages on apparatus generally increase with increasing applied voltage. Consequently suitable influence-voltage limits will of necessity be tied in with applied test voltages which will bear definite relation to the apparatus circuit voltage. When this is done, all apparatus used on the same circuit will have a common standard test voltage. Because different kinds of apparatus have different rating bases, it has been found necessary to work out a common basis for as wide a range of apparatus types as possible.

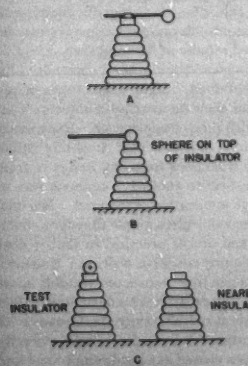

Figure 4. Radio-influence voltage tests on pedestal insulators

Table IX. Radio-Influence Voltage Measurements on Insulators (Effect of Field Configuration)

Radio-Influence Voltage in Microvolts

1 Test Voltage Applied (Kv—Rms)	2 Diagram A 10-Inch Sphere	3 Diagram A 5-Inch Sphere	4 Diagram B 10-Inch Sphere	5 Diagram C 10-Inch Sphere (2d Insulator Nearby)	6 Diagram C 10-Inch Sphere (2d Insulator Grounded)	7 Diagram C 10-Inch Sphere, 2d Insulator Moved to 72 Inches
80	7	55	185	7	120	17
100	29	78	225	22	205	35
120	52	98	225	55	270	70
140	92	135	290	110	360	120
160	144	155	1,100	230	840	360

The figures of column 3 show the increase in voltage obtained with the substitution of the smaller five-inch sphere for the ten-inch. The increase is particularly pronounced for the lower voltages. In the fourth column the ten-inch sphere was located immediately on top of the insulator, resulting in a marked increase in voltage due to discharge in the crevices between hardware and porcelain. The fifth column shows that just locating an insulator nearby gives a marked increase in voltage, presumably through changes in field configuration. Grounding the second insulator further increases the voltage as shown in column 6, and moving it further away gives the expected decrease of column 7. These results are typical and show how important are the details of circuit arrangements for such tests.

It is recognized that in some cases the test voltage is less than the rated voltage of the apparatus. However, it will be found that in such cases the rating of the apparatus is not based upon the sustained voltage but upon abnormal conditions.

Table VI lists the various three-phase line-to-line circuit voltages with the corresponding line-to-neutral voltages. It gives a standard test voltage that is based on 110 per cent of the line-to-neutral circuit voltage and shows how standard apparatus normally would be applied and tested. For transformers the test voltage is 110 per cent of the maximum rated line-to-neutral voltage, which is the highest rated tap voltage for wye-connected transformers and the highest rated tap voltage divided by the square root of 3 for delta-connected transformers, but shall not exceed the highest values in column IV for the insulation class of the winding of column III. These values have been standardized by NEMA and appear to the extent required in the appropriate high-voltage-apparatus publications to which reference should be made for specific types.

VII. Insulators

Experience in the fields of apparatus and line insulators has indicated these to be occasional sources of radio interference. Probably the most common case is that wherein a radio-influence voltage results from the breakdown of a small air gap between tie wire and insulator or sparkover in a crevice of a defective insulator. Particular defective insulator units must be located and removed. Generally plain pin-type units will produce not more than the levels of influence voltage shown in Table VII.

In many localities well-served by broadcasting stations, plain pin-type insulators have been used satisfactorily. However, the values of Table VII are substantially above the apparatus limits of Table III. Accordingly, insulator users and manufacturers have directed attention to the reduction of radio-influence voltages for insulators. In this marked success has been achieved. One user in a locality

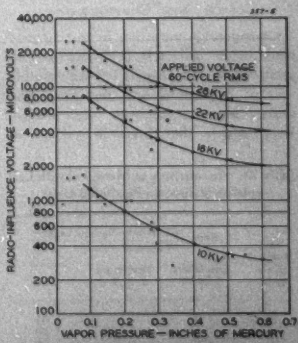

Figure 5. Variation of radio-influence voltage with humidity on high-voltage insulators

Table X. Radio-Influence-Voltage Tests on Insulators
(Effect of Paralleling Units)

Test Voltage Applied (Kv—Rms)	Insulator Units (Microvolts), Individual Tests								Paralleled Units (Microvolts)			Calculated Root-Sum-Square		
	1*	2	3	4	5	6	7	8	6-7	3, 5, 6, 7	All 8	6-7	3, 5, 6, 7	All 8
10	5,100	4,900	4,300	3,410	4,200	4,300	4,300	3,700	5,900	7,600	11,500	6,100	8,000	12,200
16	14,500	17,500	17,000	13,500	17,500	17,500	15,500	13,500	19,500	27,000	35,000	23,500	34,000	45,000
22	25,000	32,000	32,000	24,000	32,000	31,000	27,000	23,000	30,000	46,000	64,000	42,500	62,500	82,000
28	44,000	48,000	49,000	39,000	46,000	42,000	39,000	39,000	49,000	73,000	97,000	57,000	88,000	122,000

* The eight insulators used were numbered 1 to 8.

not well-served by broadcasting stations has worked out a method of applying an asphalt emulsion[12,13] to each insulator which gives very low levels. Insulator manufacturers have given considerable attention to the problem, and as a result "radio-freed" pin-type insulators are now available.

In an effort to set up reference standards significant to the levels achievable through this special design, the insulator group of NEMA has agreed upon the values of Table VIII.

Since we have two types of insulators, the plain and radio-freed, and two corresponding sets of limits for radio-noise-influence characteristics, it seems logical to assume that these limits are based upon the values it is possible to achieve under the manufacturing conditions pertaining to each type of insulator.

VIII. Radio-Influence-Voltage Variables in Apparatus Testing

As high-voltage apparatus testing for radio influence has progressed, experience has focused attention on several factors which affect apparatus levels in very pronounced measure. Among these are voltage field configurations, paralleled apparatus units, time of voltage application, and humidity.

1. Voltage Field Configurations

Considerable variation in testing may result when dielectric field distributions around test connections between supply voltage apparatus and test-piece and measurement equipment are altered. Very largely the threshold voltage at which considerable noise begins and the amount of influence voltage as dependent upon the number and extent of field-voltage gradients concentrated at particular points of small radius of curvature on the test piece or test circuit. Such field concentrations will be altered in degree with every change of circuit, and it is, therefore, important that attention be given to them in making a test setup. To illustrate this effect a brief description of a test wherein it is involved in a very conspicuous manner is given.

A pedestal insulator was being tested by arrangements shown in Figure 4. Voltages were applied to arrangements A, B, and C, and radio-influence voltages were measured. The results are given in Table IX.

2. Paralleled Units of the Same Apparatus

Radio-influence voltages generally increase when additional units of a particular type are added to the test circuit. The amount of this increase has not been confirmed by sufficient data to provide for good understanding on this point. According to local experience the custom has ranged from using the single-unit value to multiplying it by the number of units in parallel. Results of a practical test on this point are summarized in Table X.

It is obvious from these results that additional units increase the measured radio influence definitely, but that this increase is not in proportion to the number of units added. Some observation of high-voltage radio-interference phenomena by oscillograph has shown the voltage waves to be quite variable in duration, amplitude, and time of occurrence. When additional units are added, presumably crests do not correspond, or the new waves are added in time between the old. For practical purposes the method of estimating the results for added units by the root-sum-square method has been found satisfactory. This method is applied by adding the squares of individual unit results and taking the square root of this sum. Applied to the results of Table X, values as given in Table XI are obtained.

Table XI. Comparison of Measured with Calculated Values on Paralleled Units

Test Voltage (Kilovolts)	Ratio: Root-Sum-Square Value / Measured Value		
	Insulators 6 and 7	Insulators 3, 5, 6, 7	All 8
10	1.03	1.13	1.06
16	1.31	1.36	1.29
22	1.42	1.36	1.28
28	1.10	1.21	1.26
		Average ratio	1.23

It is apparent that, calculated in this manner, values somewhat higher than the combined measured values are obtained. This test shows the calculated values to range some 23 per cent higher than the measured. A value thus obtained is considered to be a good conservative estimate.

3. Time Factor in Voltage Application

Radio-influence voltage varies with time of voltage application, particularly within the first few minutes. This is illustrated by a test summarized in Table XII made on a pin-type insulator at 22 kv and at 0.34 inch of mercury atmospheric vapor pressure.

Table XII. Radio-Influence-Voltage Variation With Time of Applied Voltage

Time (Minutes)	Radio-Influence Voltage (Microvolts)
0	7,700
1	6,000
2	5,600
3	5,000
4	4,500
5	4,400
10	4,200
15	3,900
20	3,800

In this case, as is usually found with insulators, the radio-influence voltage decreased rapidly at first and then slowly, so that in some 20 minutes a constant value was obtained. Some other types of apparatus show an increasing influence voltage with time of application. Experience, therefore, indicates that, to obtain values which will check from day to day or from one test set to another, a common time of voltage application is required. The one-minute value gives ample time for a short-time test and is practical in that it does not require excessive waiting. However, the longer time values are possibly more in agreement with the continuous values consistent with service performance of apparatus. A five-minute test generally has been viewed as a good compromise and is now contained in a number of apparatus test codes.

4. Humidity

Measurement experience has shown that in many cases atmospheric humidity has a substantial effect on radio-influence voltages of apparatus. A good example is that of porcelain insulators, with which this variation may be as much as 4 to 1 over the normal range of atmospheric humidity conditions. A specimen-test result showing influence-voltage variations at several voltage levels on a standard pin-type insulator is shown in Figure 5.

This test was made in a closed chamber in which the atmosphere could be artificially reduced by suitable dryers, so that a range from 0.03 inch of mercury vapor pressure to 0.6 inch was obtained. The humidity was measured with a dew point potentiometer, and data of radio-influence voltage variations were obtained at 10 kv, 16 kv, 22 kv, and 28 kv. The marked increase in voltage as humidity decreased is consistent at all voltage levels tested. The normal test voltage for this insulator is 22 kv, and the limiting value of radio-influence voltage, 12,000 microvolts from Table VII.

Adding moisture until precipitation takes place has a varied effect. When water droplets fill in small crevices between conductor and insulation, in which local breakdown occurs, the influence voltage will decrease, because the water shifts the voltage across the crevice to other parts of the dielectric in series. But the converse of a higher influence voltage may result, if droplets form projections of small radius on an otherwise smooth surface. In this case the voltage gradient at the droplet increases, and additional local disruption gives rise to increased radio-influence voltage. Humidity then is another factor contributing to influence voltage level which must be reckoned with in testing and considered in cases of field interference.

IX. Conclusions

1. Use of the present available radio-noise meters when utilized only with the internal calibrator gives results within ±50 per cent in measurements on sine waves of radio frequency.

2. Use of a sine-wave signal generator to calibrate the noise-meter results in marked improvement and permits obtaining checks on sine waves of radio frequency to within eight per cent.

3. Even when calibrated on a signal generator, the results with different radio-noise meters, when used to measure on a given square wave, may differ by 37 per cent. Differing types of apparatus noise also result in similar meter differences.

4. As an improved instrument-performance specification, it is recommended that one or more calibration waves of varied and representative shapes be adopted.

5. Limits for the radio-influence voltage of apparatus derived on the basis of apparatus measurement and field experience are given in Table III. These are the same as the values adopted by many sections of NEMA for high-voltage apparatus.

6. To bridge the gap between radio-influence voltages of apparatus measured in the factory and noise measured on a radio-receiver set, a series of values is found valuable. These ratios are—

(*a*). Apparatus-to-on-line ratio, 1.5 to 1.

(*b*). On-line-to-under-line ratio, 70 to 1.

(*c*). Under-line-to-receiver-antenna ratio, 3.2 to 1.

(*d*). Signal-to-noise ratio, 32 to 1.

7. Apparatus limits for radio-influence voltage given in Table III and derived on the basis of apparatus measurement and field experience agree with limits as found through the use of field measurements and ratios as in conclusion 6.

8. Based on these ratios and assuming an antenna signal strength of 500 microvolts per meter and a signal-to-noise ratio of 32 to 1, a relative radio-influence voltage level for apparatus limits is derived. This level agrees with those of Table III based on factory tests and field experience.

9. To provide for the testing of all apparatus used on the same circuit, a standard set of test voltages for many types of high-voltage apparatus has been standardized as given in Table VI.

10. Factors which must be controlled in the measurement of radio-influence voltage in apparatus are voltage field configurations, number of test parts in parallel, time of voltage application, and humidity. To provide good measurement checks, these factors should be included in individual apparatus test codes.

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Open-Delta Transformer Banks—Analysis of Circuit

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FELLOW AIEE

WHEN a three-phase transformer bank is operated in open delta, an unbalanced secondary voltage results, and the transformers themselves may be overloaded. The unbalanced voltage will cause a circulating current to flow which may cause overheating of the equipment in the secondary circuit to an extent depending upon the amount of the voltage unbalance and the load being carried. Wolf and Mattison[1] have described a method of overcoming the voltage unbalance, and this paper is written to mention briefly the effect of unbalanced voltages on the operation of induction motors and to present an analysis of the circuit, together with some correlated material.

Open-delta operation of transformers will set up negative-sequence voltages in the secondary circuit which may cause increased heating of induction motors. Whether or not this increased heating is serious depends upon the load being carried by the motors and their temperature-rise characteristics.

The unbalance of the secondary voltages can be reduced to a negligible value by the addition of capacitance to the circuit, and a method is given of estimating the required amount and its distribution.

Existing methods of calculating regulation of open-delta transformer banks are not suitable for the analysis of this problem, and a new method is presented together with a method of calculating the positive and negative components of the current necessary for the application of the new method.

Effect of Unbalanced Voltages on Motor Operation

The unbalanced voltages resulting from open-delta operation are detrimental to the operation of induction motors in the secondary circuit and result in a reduction in torque and an increase in heating. The amount of voltage unbalance depends, not only upon the reactance of the transformer, but also upon the magnitude and type of load. The greatest unbalance will occur when all the load is static and the least when all the load is rotating. However, a given negative-sequence reactance applied to an induction motor produces a definite negative-sequence current of a magnitude depending only upon the characteristics of the motor.

There is a reduction in torque, because the positive-sequence voltage applied to the motor is reduced. For example, in Figure 4 of the Wolf–Mattison paper, the positive-sequence line-to-neutral secondary voltage for the closed-delta case is 335.2 volts, with an applied line-to-line equivalent voltage of 615 volts, and it is reduced to 319.8 volts for the open-delta case, with line-to-line equivalent voltage of 622. This represents a reduction in torque of nine per cent, and, in addition, the negative-sequence voltage introduces a small (usually negligible) torque in the reverse direction. Since the required mechanical output is unchanged, the current must increase to maintain the load, and increased heating results.

The unbalanced regulation of the open-delta bank introduces a negative-sequence voltage which, in turn, causes negative-sequence current to flow, and a further increase in heating results. The negative-sequence impedance of induction motors may be in the order of 10 to 25 per cent, so that a relatively small per-unit negative-sequence voltage causes a relatively larger current to circulate. The increase in losses is illustrated in Figure 1 for two types of induction motors. A ten per cent negative-sequence voltage may cause an increase in total loss, ranging from 33 to 93 per cent at full load, depending upon the characteristics of the motor.

The extra loss is revealed as increased heating in the motor. If the excess loss were evenly distributed among the three phases, the overheating would be proportional roughly to the excess losses. However, the current unbalance is such that the overcurrent flows through one phase of wye-connected motors or through two phases of delta-connected motors, resulting in local overheating and relatively greater excess temperatures than indicated by the over-all excess losses.

Whether or not this overheating is serious will depend upon the loading of the motor and the closeness of the design. If the motor is underloaded or has a liberal margin in the temperature-rise performance, the increased heating probably will not be harmful. If, however, the motors are fully loaded and already operating at a temperature close to the maximum temperature for which a reasonable length of life may be expected, the overheating caused by the excess losses may be disastrous.

Regulation of Open-Delta Transformer Banks

The usual approximate formulas[2] given for the calculation of the regulation of open-delta transformer banks are derived upon the assumption of balanced voltages and currents. Since this condition does not exist in the secondary circuit of an open-delta bank, the results are in error to a greater or less degree, and the formulas cannot be used for an analysis of this nature.

The regulation of an open-delta transformer bank may be developed as follows. See Figure 2, Figure 3a, and Figure 8.

The voltage and current relationships are

$$\begin{aligned} E_{AB} &= E_{ab} + I_{ab}Z_t & I_{ab} &= I_B \\ E_{BC} &= E_{bc} + I_{bc}Z_t & I_{bc} &= 0 \\ E_{CA} &= E_{ca} + I_{ca}Z_t & I_{ca} &= -I_C \end{aligned} \qquad (1)$$

and from these

$$\begin{aligned} E_{AB} &= E_{ab} + I_B Z_t = E_{ab} + e_{ab} \\ E_{BC} &= E_{bc} + (I_C - I_B)Z_t = E_{bc} + e_{bc} \\ E_{CA} &= E_{ca} - I_C Z_t = E_{ca} + e_{ca} \end{aligned} \qquad (2)$$

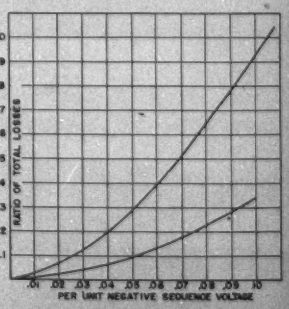

Figure 1. Variation in total loss of two types of induction motors caused by negative-sequence voltage

Motors maintain full mechanical output, and positive-sequence voltage decreases

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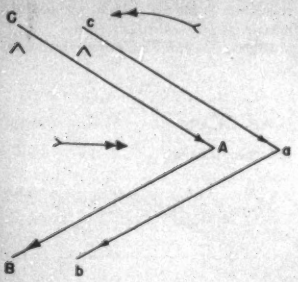
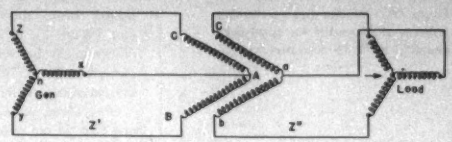
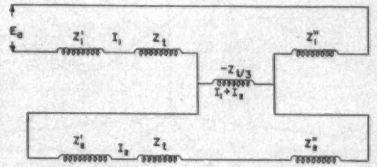


Figure 2 (left). Representation of open-delta transformer bank with direction of power flow indicated



3a



3b

Figure 3 (right). Representation of complete circuit with open-delta transformer bank and the corresponding equivalent circuit

In the foregoing it is presumed that the phase angle of I_B in reference to E_B, and so forth, is known.

If we write

$$\begin{aligned} e_{ab} &= I_B Z_t & &= (I_{B1}+I_{B2})Z_t \\ e_{bc} &= (I_C - I_B)Z_t & &= (I_{C1}-I_{B1}+I_{C2}-I_{B2})Z_t \\ e_{ca} &= -I_C Z_t & &= -(I_{C1}+I_{C2})Z_t \end{aligned} \qquad (3)$$

it can be shown easily from formula 3 and Figure 8 that

$$e_{ab1} = \frac{(-1+a^2)(2I_{A1}-I_{A2})}{3} Z_t$$

and

$$e_{a1} = \frac{2I_{A1}-I_{A2}}{3} Z_t \qquad (4)$$

$$e_{ab2} = \frac{(-1+a)(-I_{A1}+2I_{A2})}{3} Z_t$$

and

$$e_{a2} = \frac{-I_{A1}+2I_{A2}}{3} Z_t$$

and also

$$\begin{aligned} e_a &= \frac{I_{A1}+I_{A2}}{3} Z_t & &= \frac{I_A}{3} Z_t \\ e_b &= \frac{(2a^2-a)I_{A1}+(2a-a^2)I_{A2}}{3} Z_t \\ &= \frac{2I_B-I_C}{3} Z_t \qquad (4a) \\ e_c &= \frac{(2a-a^2)I_{A1}+(2a^2-a)I_{A2}}{3} Z_t \\ &= \frac{2I_c-I_B}{3} Z_t \end{aligned}$$

From formula 4 and Figure 3a we can write the expressions for the total positive and negative voltages in the circuit. They are

$$\begin{aligned} E_a &= I_1\left(Z_t+\frac{2Z_t}{3}\right)-I_{a2}\frac{Z_t}{3} \\ 0 &= -I_1\frac{Z_t}{3}+I_2\left(Z_2+\frac{2Z_t}{3}\right) \end{aligned} \qquad (5)$$

These expressions, formula 5, yield the equivalent circuit shown in Figure 3b. It is interesting to note that this is identical with the equivalent circuit for open-delta transformer banks originally developed by Edith Clarke in 1934 using an entirely different approach.

The sequence currents may be calculated as follows:

$$I_{a1} = E_a \frac{Z_2+\frac{2}{3}Z_t}{D} \qquad (6)$$

$$I_{a2} = I_{a1}\frac{Z_t/3}{Z_2+\frac{2}{3}Z_t} \qquad (7)$$

in which

$$D = \left(Z_1+\frac{2}{3}Z_t\right)\left(Z_2+\frac{2}{3}Z_t\right)-\frac{1}{9}Z_t^2 \qquad (8)$$

Z_1 = positive-sequence impedance external to the transformer

Z_2 = negative-sequence impedance external to the transformer

Again we write from formulas 2 and 3

$$\begin{aligned} E_{AB} &= E_{ab}+I_{B1}Z_t+I_{B2}Z_t \\ E_{BC} &= E_{bc}+(I_{C1}-I_{B1})Z_t+(I_{C2}-I_{B2})Z_t \\ E_{CA} &= E_{ca}-I_{C1}Z_t-I_{C2}Z_t \end{aligned} \qquad (9)$$

In the foregoing the voltage drop in the open-delta bank between the primary and secondary windings is made up of the drop resulting from two symmetrical currents. Also, we may look upon the primary voltages as those existing before the transformers are loaded, and therefore they are a set of symmetrical voltages.

This permits a simplification in the expression to the following:

$$\begin{aligned} E_{ab} &= E_{AB}-(I_{A1}Z_t\epsilon^{j(\phi+\theta_1+30)}+I_{A2}Z_t\epsilon^{j(\phi+\theta_2-30)}) \\ E_{bc} &= E_{BC}-(\sqrt{3}I_{A1}Z_t\epsilon^{j(\phi+\theta_1)}-\sqrt{3}I_{A2}Z_t\epsilon^{j(\phi+\theta_2)}) \\ E_{ca} &= E_{CA}-(I_{A1}Z_t\epsilon^{j(\phi+\theta_1-30)}+I_{A2}Z_t\epsilon^{j(\phi+\theta_2+30)}) \end{aligned} \qquad (10)$$

In this equation the angle ϕ is the angle of the transformer impedance, θ_1 and θ_2 are the phase angles of the positive- and negative-sequence currents, I_{A1} and I_{A2}, in reference to E_A. The angles θ and θ_2 are negative for lagging current and positive for leading current.

The foregoing equation 10 permits the determination of the voltage drop for each phase, the second term on right side of each expression. When this voltage drop is expressed on a per cent or per-unit basis, any of the conventional expressions[3] may be used to calculate the regulation, depending upon the degree of accuracy required.

In each of the foregoing equations 10 the reference vector for each secondary voltage is its respective primary voltage. On further expansion and with the usual approximations introduced, the positive-

Table I

	Measured	Derived	Measured	Derived
Kw	982	982	975	975 (982)
I_A	1,500	1,500 $\epsilon^{-j31.79}$	1,200	1,200 ϵ^{-j} [illegible]
I_B	1,180	1,130 $\epsilon^{-j147.53}$	1,150	1,150 $\epsilon^{-j137.36}$
I_C	1,110	1,110 $\epsilon^{j94.17}$	1,150	1,150 ϵ^{j} [illegible]
E_{ab}	578	578 $\epsilon^{-j115.24}$	602	602 ϵ^{-j} [illegible]
E_{bc}	538	538 $\epsilon^{j90.39}$	595	595 ϵ^{j} [illegible]
E_{ca}	545	545 ϵ^{-j} [illegible]	592	592 ϵ^{-j} [illegible]
E_A		328.8		345.1
E_B		324.9 ϵ^{-j} [illegible]		346.8 ϵ^{-j} [illegible]
E_C		305.3 ϵ^{j} [illegible]		341.0 ϵ^{j} [illegible]
I_a			700	700 ϵ^{j} [illegible]
I_b			350	350 ϵ^{-j} [illegible]
I_c			900	
I_{a1}			840	ϵ^{-j} [illegible]
I_{a2}			839	ϵ^{j} [illegible]

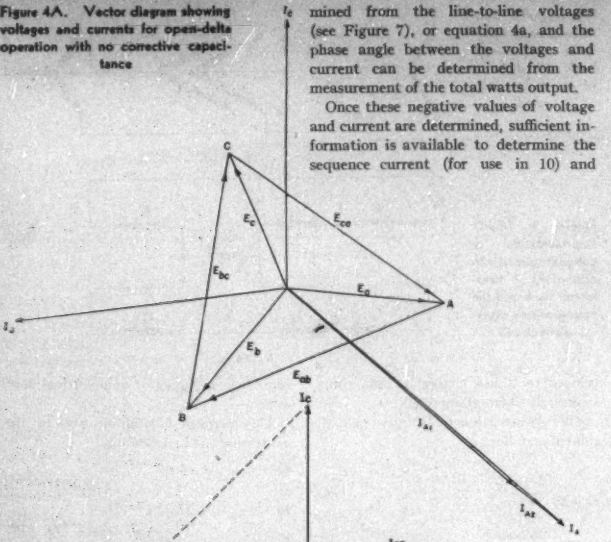


Figure 4A. Vector diagram showing voltages and currents for open-delta operation with no corrective capacitance

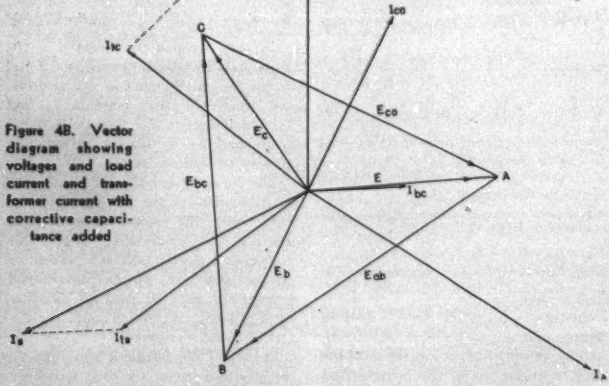


Figure 4B. Vector diagram showing voltages and load current and transformer current with corrective capacitance added

sequence parts will yield the conventional form[3] given for the calculation of the regulation of open-delta transformer banks.

Assume three voltage values E_{ab}, E_{bc}, and E_{ca}, together with three current values I_A, I_B, and I_C, have been measured. Then we can write (see Figure 7)

$$\begin{aligned} E_{ab} &= E_{ab} & I_A &= I_A \\ E_{bc} &= E_{bc}\epsilon^{-j(120-ab)} & I_B &= I_B\epsilon^{-j(120-AB)} \\ E_{ca} &= E_{ca}\epsilon^{j(120-ca)} & I_C &= I_C\epsilon^{j(120-CA)} \end{aligned} \qquad (11)$$

in which the angles are determined as indicated in Figure 7, but it should be noted fully that the voltage angle *ab* need not be the same necessarily as the current angle *AB*. The line-to-neutral voltages, E_a, E_b, and E_c, may be determined from the line-to-line voltages (see Figure 7), or equation 4a, and the phase angle between the voltages and current can be determined from the measurement of the total watts output.

Once these negative values of voltage and current are determined, sufficient information is available to determine the sequence current (for use in 10) and then to determine the per-unit impedance voltage (12 and 12a) in magnitude and phase angle, to be used in the calculation of regulation. On the other hand, if the constants of the circuit are known, the sequence currents may be evaluated by use of equations 6 and 7.

New Formula for Precise Calculation of Transformer Regulation

Some of the conventional approximate formulas[4] for regulation are subject to appreciable error when the per-unit drop is above the usual values. Accordingly, the following new method of calculating regulation is offered, which permits calculation to any desired precision.

Express one of the foregoing expressions as:

$$\begin{aligned} E_s &= E_p - (I_{b1}Z_1\epsilon^{j(\phi+\theta_1+90)} + I_{b2}Z_1\epsilon^{j(\phi+\theta_2-90)}) \\ &= E_p - E_{p2}\epsilon^{j\theta} \end{aligned} \qquad (12)$$

anb then, if we let

$$p = \frac{E_{p2}}{E_s} \qquad (12a)$$

and then

$$\frac{E_p}{E_s} = 1 + p\epsilon^{j\theta}$$

there results

$$\frac{E_p}{E_s} = 1 + p\cos\theta + jp\sin\theta \qquad (13)$$

Per-unit regulation,

$$r = \frac{E_p - E_s}{E_s} = \frac{E_p}{E_s} - 1$$

so that from equation 13

$$r = a - \frac{a^2}{2} + \frac{a^3}{2} - \frac{5}{8}a^4 + \frac{7}{8}a^5 - \frac{21}{16}a^6 + \frac{33}{16}a^7 - + \ldots \qquad (14)$$

$$a = p\cos\theta + \frac{p^2}{2}$$

The expression $p\epsilon^{j\theta} = p(\sin\theta + j\cos\theta)$ represents the per-unit impedance drop in magnitude and position. For this particular problem the proper values to use are obtained from equation 10.

By this method the regulation may be calculated to any precision justified by the supporting data, and this method has been incorporated by the writer in the latest revision of American Standard for Transformers, *C*-57.1, and was included in the report of the subcommittee responsible for the revision of section 4 of *C*-57.

Calculation of Regulation

At this point the regulation for the open-delta condition of case 2 of Figure 4 of the Wolf–Mattison paper will be

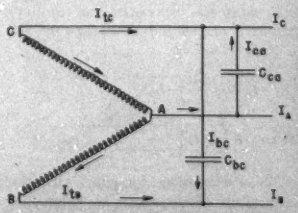


Figure 5. Secondary side of open-delta transformer bank showing phases to which corrective capacitance is added

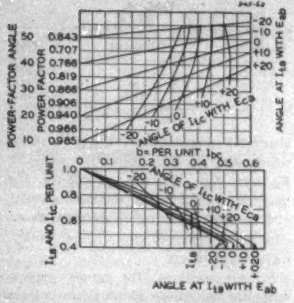

POWER-FACTOR ANGLE
POWER FACTOR
ANGLE AT I_{ca} WITH E_{ab}
b= PER UNIT I_{bc}
I_{ca} AND I_{bc} PER UNIT
ANGLE OF I_{bc} WITH E_{ca}
ANGLE AT I_{ca} WITH E_{ab}

Figure 6A. Chart showing relationship between the amount of corrective capacitance added, the resultant current in the transformer, and the phase angle between the transformer current and the transformer voltages

For $n=\frac{I_{ca}}{I_{bc}}=1^{3}/_{4}$

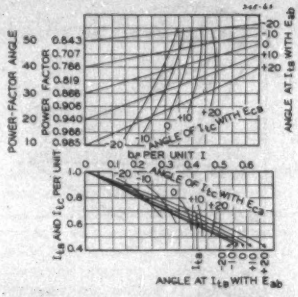

POWER-FACTOR ANGLE
POWER FACTOR
ANGLE AT I_{ca} WITH E_{ab}
b= PER UNIT I
I_{ca} AND I_{bc} PER UNIT
ANGLE OF I_{bc} WITH E_{ca}
ANGLE AT I_{ca} WITH E_{ab}

Figure 6B. Chart showing relationship between the amount of corrective capacitance added, the resultant current in the transformer, and the phase angle between the transformer current and the transformer voltages

For $n=\frac{I_{ca}}{I_{bc}}=2$

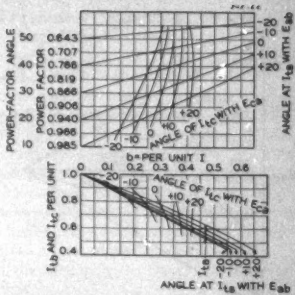

POWER-FACTOR ANGLE
POWER FACTOR
ANGLE AT I_{ca} WITH E_{ab}
b= PER UNIT I
I_{ca} AND I_{bc} PER UNIT
ANGLE OF I_{bc} WITH E_{ca}
ANGLE AT I_{ca} WITH E_{ab}

Figure 6C. Chart showing relationship between the amount of corrective capacitance added, the resultant current in the transformer, and the phase angle between the transformer current and the transformer voltages

For $n=\frac{I_{ca}}{I_{bc}}=2^{1}/_{4}$

calculated. The per-unit impedance of the transformer is 0.0592 at 522 amperes, and the impedance angle ϕ is 82.52 degrees. (All numerical values of angles are in degrees.)

Then

$I_1=(1{,}230-j8.7)\epsilon^{-j35.39}=1{,}230\epsilon^{-j35.79}$
$I_2=(270+j8.7)\epsilon^{-j35.39}=270.1\epsilon^{-j35.44}$
$Z_t=0.0592\epsilon^{j82.52}$

In the preceding equation for I_1 and I_2, the reference vector is E_a, whereas in equation 10 the reference vector is E_A. The angle between E_A and E_a may be found from the following:

$$\tan\beta=\frac{I_A Z_t \sin(\phi+\theta)}{3+I_A Z_t\cos(\phi+\theta)}$$

which gives

$\beta=0.78$

and then $\theta_1=36.48$, and $\theta_2=34.22$, so that

$\phi+\theta_1+30=76.04$

and

$\phi+\theta_2-90=41.70$

$\phi+\theta_1=46.04$

and

$\phi+\theta_2=48.3$

$\phi+\theta_1-30=16.04$

and

$\phi+\theta_2+90=138.30$

$\frac{1{,}230}{522}\times 0.0592=0.1395$

$\frac{270.1}{522}\times 0.0592=0.03064$

Then for phase AB

$p\epsilon^{j\theta}=0.1395\,\epsilon^{j78.04}+0.03064\epsilon^{-j41.76}$
$=0.0566+j0.115$
$a=0.0648$
Per-unit regulation $=0.0628$ for phase AB

And in a similar manner for the other phases there results the data shown in Table A.

This is a reasonably good check. The per-unit values are all on the basis of the rated output voltage—575 volts.

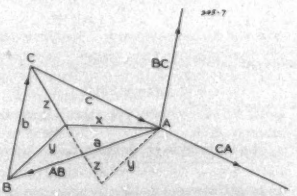


Figure 7. Vector diagram illustrating simplified method of finding line-to-neutral voltage and the positive- and negative-sequence components from a set of unbalanced line-to-line voltages, when no zero-sequence voltage is present

Analysis of Data, Figure 4 of the Wolf–Mattison Paper

In Table I is shown an analysis of the data in Figure 4 of the Wolf–Mattison paper, giving the measured and certain derived values. The phase angle between E_a and I_A is predicated upon the requirement that the calculated output of the two transformers must equal the measured value. This information is shown in Figures 4a and 4b.

The positive- and negative-sequence components for the open-delta operation, Figure 4a, are without capacitance.

$E_{a1}=319.4-j16.38$ $\qquad I_{A1}=(1{,}230-j8.7)\epsilon^{-j35.39}$

$E_{a2}=9.4+j16.83$ $\qquad I_{A2}=(\ 270+j8.7)\epsilon^{-j35.39}$

and with corrective capacitance added

$E_{a1}=344.3-j3.31$ $\qquad I_{A1}=1{,}166.5\epsilon^{-j36.59}$

$E_{a2}=0.85+j3.31$ $\qquad I_{A2}=33.5\epsilon^{-j36.59}$

$$\cos ab=\frac{a^2+b^2-c^2}{2ab} \qquad \cos xy=\frac{x^2+y^2-z^2}{2xy} \qquad \cos cx=\frac{c^2+x^2-z}{2cx}$$

Other angles in similar manner. All angles acute.

$X^2=\frac{1}{9}(2a^2-b^2+2c^2)$, $a^2=2x^2+2y^2-z^2$, and so forth

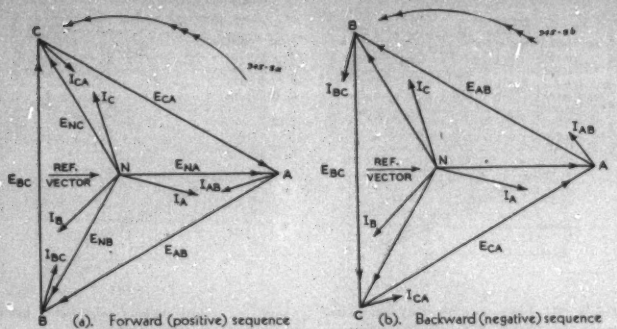
$E_{AB}=E_{AB}$ $\qquad E_a=E_a$ $\qquad E_{AB}=E_{AB}\epsilon^{-j(180-ca)}$

$E_{BC}=E_{BC}\epsilon^{-j(180-ab)}$ $\qquad E_b=E_b\epsilon^{-j(180-xy)}$ $\qquad E_{BC}=E_{BC}\epsilon^{j(ca+ab)}$

$E_{CA}=E_{CA}\epsilon^{j(180-ca)}$ $\qquad E_c=E_c\epsilon^{j(180-ax)}$ $\qquad E_{CA}=E_{CA}\epsilon^{j(ca-ax)}$

$$E_{AB1}=\frac{1}{2}E_{AB}+j\frac{1}{2\sqrt{3}}(E_{BC}-E_{CA}) \qquad jE_{AB1}=\frac{1}{2}E_{AB}-j\frac{1}{2\sqrt{3}}(E_{BC}-E_{CA})$$

$$E_{a1}=\frac{1}{2}E_{AB}+j\frac{1}{2\sqrt{3}}(E_B-E_C) \qquad jE_{a1}=\frac{1}{2}E_a-j\frac{1}{2\sqrt{3}}(E_B-E_C)$$



(a). Forward (positive) sequence (b). Backward (negative) sequence

Figure 8. Chart showing certain sequence relationships used in the text

Positive Sequence		Negative Sequence	
$E_a = E_a\epsilon^{j0} = E_a$	$I_a = \quad = I_a\epsilon^{j\theta}$	$E_a = E_a\epsilon^{j0} = E_a$	$I_a = \quad = I_a\epsilon^{j\theta}$
$E_b = E_a\epsilon^{-j120} = a^2E_a$	$I_b = I_a\epsilon^{j(\theta-120)} = a^2I_a\epsilon^{j\theta}$	$E_b = E_a\epsilon^{j120} = aE_a$	$I_b = I_a\epsilon^{j(\theta+240)} = aI_a\epsilon^{j\theta}$
$E_c = E_a\epsilon^{-j240} = aE_a$	$I_c = I_a\epsilon^{j(\theta-240)} = aI_a\epsilon^{j\theta}$	$E_c = E_a\epsilon^{j240} = a^2E_a$	$I_c = I_a\epsilon^{j(\theta+120)} = a^2I_a\epsilon^{j\theta}$
$E_{ab} = (-1+a^2)E_a$	$I_{ab} = \dfrac{I_a}{-1+a}$	$E_{ab} = (-1+a)E_a$	$I_{ab} = \dfrac{I_a}{-1+a^2}$
$= \sqrt{3}E_a\epsilon^{-j150}$	$= \dfrac{1}{\sqrt{3}}I_a\epsilon^{j(\theta-150)}$	$= \sqrt{3}E_a\epsilon^{j150}$	$= \dfrac{1}{\sqrt{3}}I_a\epsilon^{j(\theta+150)}$
$E_{bc} = (-a^2+a)E_a$	$I_{bc} = \dfrac{I_a}{-a+a^2}$	$E_{bc} = (-a+a^2)E_a$	$I_{bc} = \dfrac{I_a}{-a^2+a}$
$= \sqrt{3}E_a\epsilon^{j90}$	$= \dfrac{1}{\sqrt{3}}I_a\epsilon^{j(\theta+90)}$	$= \sqrt{3}E_a\epsilon^{-j90}$	$= \dfrac{1}{\sqrt{3}}I_a\epsilon^{j(\theta-90)}$
$E_{ca} = (-a+1)E_a$	$I_{ca} = \dfrac{I_a}{-a^2+1}$	$E_{ca} = (-a^2+1)E_a$	$I_{ca} = \dfrac{I_a}{-a+1}$
$= \sqrt{3}E_a\epsilon^{-j30}$	$= \dfrac{1}{\sqrt{3}}I_a\epsilon^{j(\theta-30)}$	$= \sqrt{3}E_a\epsilon^{j30}$	$= \dfrac{1}{\sqrt{3}}I_a\epsilon^{j(\theta+30)}$
$E_a = \dfrac{1}{\sqrt{3}}E_{ab}\epsilon^{-j150}$	$I_a = \sqrt{3}I_{ab}\epsilon^{j30}$	$E_a = \dfrac{1}{\sqrt{3}}E_{ab}\epsilon^{j150}$	$I_a = \sqrt{3}I_{ab}\epsilon^{j30}$
$E_b = \dfrac{1}{\sqrt{3}}a^2E_{ab}\epsilon^{j150}$	$I_b = \sqrt{3}a^2I_{ab}\epsilon^{j30}$	$E_b = \dfrac{1}{\sqrt{3}}aE_{ab}\epsilon^{-j150}$	$I_b = \sqrt{3}aI_{ab}\epsilon^{j30}$
$E_c = \dfrac{1}{\sqrt{3}}aE_{ab}\epsilon^{j150}$	$I_c = \sqrt{3}aI_{ab}\epsilon^{j30}$	$E_c = \dfrac{1}{\sqrt{3}}a^2E_{ab}\epsilon^{-j150}$	$I_c = \sqrt{3}a^2I^{j30}$
Use subscript 1, for example, E_{a1}		Use subscript 2, for example, E_{a2}	

In these expressions E_a is the reference vector.

From these data it is seen that open-delta operation in this particular case introduces 6 per cent negative-sequence voltage, which in turn introduces a 22 per cent negative-sequence current.

In Figure 4b the voltage and load currents are seen to be closely balanced, and this has been accomplished by the addition of capacitance current in certain proportions (see Figure 5) as described by Wolf and Mattison.

The current I_B in the leading phase AB has been advanced slightly in phase (Figure 4b), and thus its phase angle is reduced in reference to the voltage AB, and at the same time it is reduced in magnitude. The current I_C in the leading phase has been advanced greatly in phase, and this also reduces its (reversed) phase angle in reference to the voltage CA and, at the same time, its magnitude. After this modification has been made, current I_{bc} leads its voltage E_{ab} by 1.99 degrees and the current I_{ca}, reversed, lags its voltage E_{ca} by 13.19 degrees. Since the power factor is now practically unity, the difference in regulation is so slight that the negative-sequence voltage introduced has a negligible effect.

The relative values of capacitance current that need be added will depend upon the power factor and magnitude of the load. The required amount and its distribution cannot be determined readily by a study of the unbalanced condition. Rather the line currents I_B and I_C *for balanced three-phase conditions* must be modified so that the respective transformer currents, I_{LB} and I_{LC}, are not only approximately equal in magnitude, but also have approximately the same phase relationship to their respective voltages, E_{ab} and E_{cb}. By this procedure the unequal regulation is reduced greatly, and thereby the cause of the unbalanced current is removed and, consequently, its harmful effects.

Strictly speaking, the proper capacitance for one power factor is not correct at other power factors. In Figure 6 are given curves (see also Figure 5), by which the amount of corrective capacitance may be estimated, and it should be borne in mind that precision is not necessary.

In these curves b is the per-unit capacitive current, based on actual load current, added across phase bc, and nb represents the capacitive current added across phase ca, with n having values of $1^1/_3$, 2, and $2^1/_3$.

These charts are used as follows: Assume the power factor of the load is 0.77, assume b to be 0.35 as the first trial, and n as $1^1/_3$. Then the intersection of the line for power factor = 0.77 and $b=0.35$ indicates an angle of about $+1.5$ degrees for I_{BC} and of about -24 degrees for I_{LB} on the upper chart. Now locate these angles respectively on the lower chart for the assumed values of $b=0.35$; I_{BC} is indicated as about 0.71, and I_{LB} is indicated as about 0.65. This amount of correction probably would not be satisfactory, and a new trial should be made with a different b or different n, or with both different.

For a further example, assume a load having a power factor of 0.81 or $\theta=36$ degrees. Then we can get the results from the curves as shown in Table II.

With the possible exception of the first entry, any of the foregoing will give sufficient reduction in the unbalance to assure satisfactory operation of the induction motors on the secondary circuits. Incidentally, the fourth entry

Table A

Phase	Calculated	Test
AB	0.0628	0.0765
BC	0.1407	0.146
CA	0.1120	0.1373

Table II

n	b	θ_{LB}	θ_{LC}	I_{LB}	I_{LC}
$1^1/_3$	0.3	+4	−21	0.730	0.725
$1^1/_3$	0.35	+6	−13	0.690	0.710
$1^1/_3$	0.4	$+8^1/_2$	− 3	0.655	0.755
2	0.3	+4	$-13^1/_2$	0.730	0.700
2	0.35	+6	− 3	0.690	0.730
2	0.4	$+8^1/_2$	$+6^1/_2$	0.655	0.750
$2^1/_3$	0.3	+4	− $5^1/_2$	0.730	0.665
$2^1/_3$	0.35	+6	+ 4	0.690	0.640
$2^1/_3$	0.4	$+8^1/_2$	$+15^1/_2$	0.655	0.660

Skin Effect in Bimetallic Conductors

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Synopsis: Mathematical expressions for a-c impedance and current distribution are derived for bimetallic conductors with circular symmetry. The results are illustrated by application to a copper-covered steel conductor in the frequency range up to 160 kilocycles. Measurements of the a-c resistance in the same frequency range provide a check on the theoretical results. The studies made on the copper-covered steel conductor indicate that its resistance is substantially that of its tubular copper portion alone and, for all but the lowest frequencies, may be taken from the simpler formulas and curves already available for tubes.

BIMETALLIC conductors consisting of a copper covering welded to a steel core are widely used for power and communication lines, because the great tensile strength of these conductors permits long pole spans. The resistance of such bimetallic conductors at power frequencies is known.[1] A knowledge of the resistance at higher frequencies, in the range up to 150 kilocycles, has become important for designing and for determining the performance of carrier-current communication systems operated over bimetallic conductors.

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The authors acknowledge the contributions of two previous Buhl research fellows: H. E. Webb, Jr., who made a preliminary experimental study of the subject in his master of science thesis, and A. G. Williamson who made numerous measurements and aided in the development of the experimental technique. The conductors used in the tests were supplied by the Copperweld Steel Company.

A previous study[2] of this subject was published in 1915 by J. M. Miller, who gave an approximate method of calculating a-c resistance and compared calculated with experimental results for several specimens of conductors in the frequency range up to three kilocycles. However, his method of calculation is based upon the assumption that the current density in the outer layer of copper is uniform, which, although it is an excellent approximation at low frequencies, departs considerably from the actual condition at high frequencies.

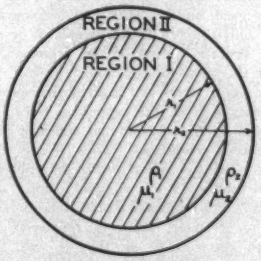

Figure 1. Section of bimetallic conductor

It is the purpose of this investigation to develop a more exact theory of skin effect for bimetallic conductors with circular symmetry, to illustrate the theory by using it to calculate for a particular copper-covered steel conductor the ratio of a-c resistance to d-c resistance and the current distribution over a range of frequencies, and to check the theory by an experimental determination of the resistance ratio for the same conductor over the selected range.

Theoretical Expression for A-C Impedance

In what follows, a general relation is developed for the a-c impedance of a conductor which has the section shown in Figure 1. The interior region I has resistivity ρ_1 and permeability μ_1; the exterior region II, ρ_2 and μ_2. The developed relation applies to all other bimetallic conductors of circular section, including aluminum-covered steel, as well as to copper-covered steel.

In developing the theory it is assumed that:

1. Each region is homogeneous; that is, within each region the permeability and resistivity do not vary from point to point.
2. At any point the permeability and resistivity do not vary with time.
3. The bounding surface between regions and the outer surface are circular cylinders.
4. The conductor carries a sinusoidal current.
5. The conductor is very long and straight and the return conductor or conductors are either concentric tubes or at such remote distances that they produce no appreciable field within the conductor considered.

The derivation of the expression for the ratio of a-c impedance to d-c resistance is outlined in Appendix A. The expression itself, in convenient form for calculation, is:

$$\frac{Z_{ac}}{R_{dc}} = \frac{br_2}{2j} P \operatorname{conj} \left[\frac{A - \frac{F}{H}C - IGA + \frac{IE}{H}C}{B - \frac{F}{H}D - IGB + \frac{IE}{H}D} \right] \quad (1)$$

in which P is the per-unit conductivity (per cent conductivity divided by 100), and each of the nine quantities A to I is a Bessel function expressed as a complex number, except for G and I, which are quantities simply obtained from Bessel functions. Other forms of Bessel functions may be employed, the present forms being selected for convenience in

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is the case covered by Figure 4 of the Wolf–Mattison paper, and the check is very good. In selecting the particular values of corrective capacitance the power factor and range of load are the factors to be considered.

Appendix

1. If there is no zero-sequence voltage in the system, then the proper neutral point of the system is the intersection of the medians of the closed line-to-line voltage triangle. This can be proved easily by geometric relationships and is true, because the line-to-neutral voltages must form a closed triangle of themselves and therefore fix the line-to-line triangle in such a way that any line-to-neutral voltage if extended, will bisect the opposite side. These relationships are set forth in Figure 7, which gives a direct method of calculating the line-to-neutral voltages from the line-to-line voltages when there is no zero-sequence voltage. Also, a more direct method of determining the positive- and negative-sequence components is given.

2. In Figure 8 are shown certain sequence relationships to which reference was made in the test.

References

1. MOBILE CAPACITOR UNITS FOR EMERGENCY LOADING OF TRANSFORMERS IN OPEN DELTA, H. B. Wolf, G. G. Mattison. AIEE TRANSACTIONS, volume 62, 1943, February section, pages 83-6.

2. TRANSFORMER ENGINEERING (book). John Wiley and Sons, New York, N. Y. Page 181.

3. American Standard for Transformers, C-57.1.

Table I. Equivalent Forms of Bessel Functions

$I_0(j^{3/2}z) = \text{ber } z + j \text{ bei } z$	$=$	$= J_0(j^{3/2}z)$	$= \text{conj } J_0(j^{3/2}z)$	$= M_0 \epsilon^{j\theta_0}$
$I_1(j^{3/2}z) = \frac{1}{j}(\text{ber}_1 z + j \text{ bei}_1 z) = \frac{1}{j^{3/2}}(\text{ber}' z + j \text{ bei}' z) = \frac{1}{j^{3/2}}\frac{d}{dz}J_0(j^{3/2}z) = j \text{ conj } J_1(j^{3/2}z)$				$= \frac{1}{j} M_1 \epsilon^{j\theta_1}$
$K_0(j^{3/2}z) = \text{ker } z + j \text{ kei } z$	$=$	$=$	$= \frac{\pi}{2j} \text{conj } H_0^{(1)}(j^{3/2}z)$	$= N_0 \epsilon^{j\phi_0}$
$K_1(j^{3/2}z) = j(\text{ker}_1 z + j \text{ kei}_1 z) = j^{3/2}(\text{ker}' z + j \text{ kei}' z)$		$=$	$= -\frac{\pi}{2} \text{conj } H_1^{(1)}(j^{3/2}z) = jN_1 \epsilon^{j\phi_1}$	

See references 3, 6, and 7.

using the Jahnke–Emde tables.[3] The quantities are defined as follows:

$$
\begin{aligned}
&\omega = 2\pi f && A = J_0(j^{3/2}br_3)\\
&= \sqrt{-1} && B = j^{3/2}J_1(j^{3/2}br_3)\\
&a = \sqrt{\frac{\omega\mu_1}{\rho_1}} && C = H_0^{(1)}(j^{3/2}br_3)\\
&&& D = j^{3/2}H_1^{(1)}(j^{3/2}br_3)\\
&b = \sqrt{\frac{\omega\mu_2}{\rho_2}} && E = J_0(j^{3/2}br_3)\\
&&& H = H_1^{(1)}(j^{3/2}br_3)
\end{aligned}
\qquad (2)
$$

$$F = J_1(j^{3/2}br_3)$$

$$G = \frac{H_0^{(1)}(j^{3/2}br_3)}{H_1^{(1)}(j^{3/2}br_3)}$$

$$I = \sqrt{\frac{a\rho_1}{\mu_1\rho_1}} \times \frac{J_1(j^{3/2}ar_1)}{J_0(j^{3/2}ar_1)}$$

$$P = 1 - \left[\frac{r_1}{r_3}\right]\left[1 - \frac{\rho_2}{\rho_1}\right]$$

In the above expressions the meter-kilogram-second system of units[1] is employed.

The real component of Z_{ac}/R_{dc} is the ratio of a-c to d-c resistance; the imaginary component is the ratio of the reactance arising from the flux within the conductor to the d-c resistance.

The first terms of the numerator and denominator, A and B, are the largest terms for the cases that have been calculated and can be taken from the tables directly in Cartesian form. The other terms within the brackets, which are products and quotients, are obtained conveniently in polar form. Thus the arrangement in equation 1 is such that accuracy is not lost in the most important terms by writing them as the products of various factors, each of which, taken from a table, has some uncertainty in the last decimal place. Also if a slide rule is to be used, multiplication and division are required only in the less significant terms.

Another feature of the arrangement of the terms in equation 1 is that, by dropping terms and making appropriate changes in P, the expression gives the ratio Z_{ac}/R_{dc} for solid and hollow homogeneous conductors. Thus, if only the first terms A and B within the brackets are used, and if P is set equal to unity, the expression applies to a solid homogeneous wire of outer radius r_3, resistivity ρ_2, and permeability μ_2: that is, with the characteristics of the outer material. Likewise, if only the first two terms of the numerator and the first two terms of the denominator are used with P corresponding to an infinite value of ρ_1, the expression applies to a tubular conductor of inner and outer radii r_1 and r_2 made of the outer material.

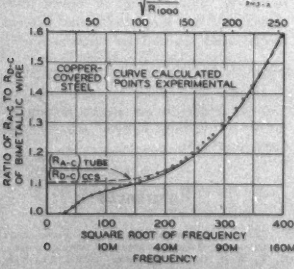

Figure 2. Ratio of a-c to d-c resistance, number 10 American wire gauge copper-covered steel, 40 per cent conductivity wire at 29 degrees centigrade

Application of the Theory

To illustrate the use of equation 1 and to obtain calculated values of the ratio of R_{ac} to R_{dc} for comparison with experimental ones, the equation is applied to a particular specimen of number 10 American wire gauge copper-covered steel 40 per cent conductivity wire supplied by the Copperweld Steel Company.

The quantities r_1, r_2, ρ_1, ρ_2, and μ_1 were carefully determined for the conductor used. The value of r_3, the outer radius, was found from the average of a large number of micrometer measurements; ρ_1, the resistivity of the steel core material, was found from Kelvin-bridge measurements after the copper was removed chemically from the composite wire; ρ_2, the resistivity of the copper sheath, was taken from tables. The value of r_1 was calculated from the measured d-c resistance of the composite conductor and the previously determined values of r_3, ρ_1 and ρ_2. The permeability μ_1 of the core was determined from inductance measurements. For this purpose short lengths of the steel core were drilled and arranged for stringing, as cylindrical beads, on a small insulated wire with coaxial return. The inductance of the wire with and without the steel beads was measured by means of an inductance bridge, and from these measurements and the dimensions the permeability was calculated.

The following values were found:

$r_1 = 0.1024 \times 10^{-2}$ meter
$r_3 = 0.1303 \times 10^{-2}$ meter

$\rho_1 = 27.91 \times 10^{-8}$ ohm-meter
$\rho_2 = 1.830 \times 10^{-8}$ ohm-meter

$\mu_1 = 78.8 \times 4\pi \times 10^{-7}$
$\mu_2 = 1.0 \times 4\pi \times 10^{-7}$

The calculated ratio of a-c to d-c resistance as a function of frequency for a conductor with the above constants is shown by the solid curve in Figure 2. Values of frequency were chosen that would minimize the necessity for interpolation in the tables of Bessel functions.

When the scale of abscissas is expressed in terms of $\sqrt{f/R_{dc}}$ the curve of Figure 2 will apply to a conductor of any size, provided it is made of the same materials as the one for which the figure was calculated and has the same ratio of r_1 to r_3. These conditions also imply the same per cent conductivity. Such a scale is given

Figure 3. Photomicrograph of section of copper-covered steel wire

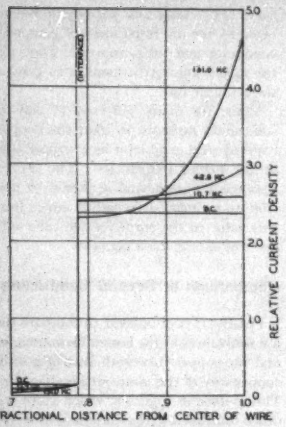

Figure 4. Variation of current density with distance from center of wire

at the top of the figure, R_{1000} being the d-c resistance in ohms per thousand feet.

Experimental Verification

The points in Figure 2 were obtained experimentally by the method described in Appendix B.

The agreement between calculation and experiment is everywhere at least within 1½ per cent, at most frequencies is closer, and thus is well within most commercial tolerances. The experimental results are believed to be accurate to one quarter of one per cent; the calculations to one tenth of one per cent. The small discrepancies between calculated and test values are thought to have their origin in the departure of the actual conductor from the assumptions made in the analysis. In the particular specimen studied the section of the steel core is not exactly circular as may be seen from the photomicrograph of Figure 3. Also, micrometer measurements of the steel core, from which the surrounding copper had been removed chemically, showed a section of roughly elliptic form of major axes 0.075 and 0.085 inch. Another important departure from the assumptions lies in the nonhomogeneity of the copper. In the manufacture of copper-covered steel conductors, molten copper is poured around a steel core, and the resulting billet is rolled into rod and then drawn into wire. There is evidence that some iron migrates into the copper at the junction of the two metals, and the presence of even small amounts of iron causes an increase in the resistivity of the copper, this increase, however, probably being restricted to the immediate neighborhood of the interface.

Current Distribution

The current distribution over the section of the conductor, that is, the current density as a function of radial distance, is given by expressions that are derived in Appendix A. The result is shown in Figure 4, in which there is given a curve proportional to the magnitude of current density for frequencies of zero, 10.7, 42.8, and 131 kilocycles. Current densities are shown in only the outer portion of the conductor, the current density being small and unimportant in the interior regions at most frequencies. The curves are drawn to show the relative current densities on the assumption that the total current is the same at each of the four frequencies. Thus, as the frequency is increased, the current density in the interior falls with respect to that at the outer surface, and, to maintain the same total current, the density at the outside surface must increase, and this change results in a larger voltage drop per-unit length. In fact, the impedance drop per-unit length, exclusive of that part originating in flux linkages outside of the conductor, is proportional to the current density at the outside surface. Since the current is assumed to be the same for all frequencies Z_{ac}/R_{dc} is also proportional to this density, shown by the ordinate at extreme right of Figure 4.

The scale of ordinates for Figure 4 is chosen so that if the total current were distributed uniformly over both the steel and copper of the conductor, unit current density would result. In terms of this unit, at zero frequency the current density in the steel is 15.5 per cent, in the copper 236 per cent, the average, weighted with respect to area, being 100 per cent. On the other hand, at the highest frequency of the figure, 131 kilocycles, the current density at the center is substantially zero, on the steel side of the interface it is 15 per cent (nearly the same as before), on the copper side of the interface 231 per cent, and at the outside surface 464 per cent. If the current densities were averaged over the area of the conductor and account were taken of the variation of phase as well as magnitude, the result would again be 100 per cent.

The regularity of the changes with increase of frequency is not apparent from Figure 4; therefore, curves, showing the magnitude of the current density G_2 at the outside and G_1 at the copper side of interface, as functions of frequency are given in Figure 5, in which the current densities are expressed in terms of the average current density as used in Figure 4. Figure 5 also gives the phase of the current density at the interface and at the outer surface with respect to the total current in the conductor. For the interface the angles are lagging; for the surface, leading.

Since the steel carries but a small fraction of current, the most convenient criterion of the extent of skin effect is the ratio of the extreme magnitudes of current density in the copper: that is, of the ratio of interface density to surface density. This is given in Figure 6, together with another curve showing the angle by which the interface current density lags the surface density. Thus, as is shown in the figure, the change of phase from the inside to the outside of the copper is zero for direct current, 10 degrees for 10.3 kilocycles, and 82 degrees for 131 kilocycles. The corresponding change of phase, not shown in the figure, from the interface to the center of the steel core is zero for direct current, 182 degrees for 10.3 kilocycles, and 727 degrees for 131 kilocycles.

Figures 4, 5, and 6 are expressed in terms of frequency or its square root and apply to the specific conductor under consideration. However, they, like Figure 2, could be generalized to apply to any other conductor of different radius but of the same materials and with the same per cent conductivity.

The study of current distribution throws light upon the reasons for the small departures of the theoretical curve from

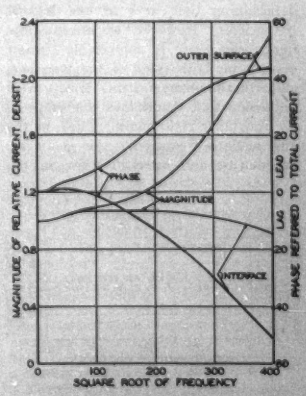

Figure 5. Magnitude and phase of current densities at interface and outer surface

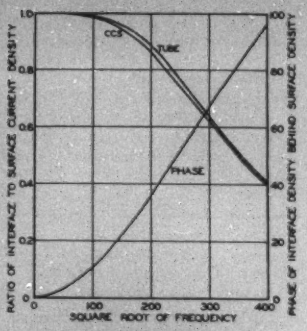

Figure 6. Ratio of interface to surface current density, and corresponding phase difference

the experimental points in Figure 2. The fact that these departures occur at intermediate frequencies rather than at the extremes indicates that they probably are caused by inaccuracies associated with the interface. At zero frequency there is no error, because the constants are made to agree with d-c measurements. At low frequencies, below ten kilocycles, the rise in the resistance ratio is caused by a decrease of current density in the steel core. The decrease is greatest at the center, and there is little change at the interface or in the copper; thus, conditions at the center determine the shape of the curve at the low frequencies. On the other hand, at the highest frequencies, 100 to 160 kilocycles, the current density in the steel is negligible, and that in the interface region is overshadowed by the higher current densities at the outside surface; thus, conditions at the outside surface are predominant in determining the curve at the highest frequencies. However, at intermediate frequencies there is appreciable current density on both sides of the interface, and it is the change of this density with frequency that determines the shape of the resistance ratio curve. Thus, at the intermediate frequencies the geometric irregularity and interfacial rise in the copper resistivity would have their greatest effect. The small discrepancies at the highest frequencies may be caused by the lack of agreement between the table value and the actual value of the resistivity of copper. At these frequencies inaccuracies in the constants ρ_1 and μ_1 of the iron have but little effect on the calculated values of R_{ac}/R_{dc}.

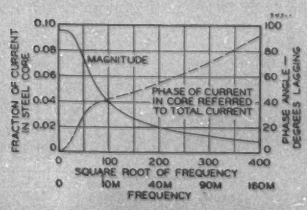
FRACTION OF CURRENT IN STEEL CORE
PHASE ANGLE — DEGREES LAGGING
MAGNITUDE
PHASE OF CURRENT IN CORE REFERRED TO TOTAL CURRENT
SQUARE ROOT OF FREQUENCY
FREQUENCY

Figure 7. Magnitude and phase of the fraction of total current carried by steel core

Approximate Method of Determining A-C Resistance

The fact that but a small portion of the current flows in the steel core of the conductor in the special case studied, only 9.5 per cent even at zero frequency, suggests a simple approximate method of determining the a-c resistance of such a conductor, a method in which the current in the steel is neglected entirely and the resistance of the copper-covered steel conductor taken as the resistance of the tubular copper shell alone. This latter resistance is well known, is obtainable from relatively simpler formulas,[4] and is to be found conveniently in general curves.[4,5]

The accuracy of this method depends upon two conditions: that the current in the steel core contributes but little to the total current, and also that it has a negligible effect on the current distribution in the copper.

The fraction of the total current that is carried in the steel core is shown in Figure 7; also is shown the lagging phase angle of the total current in the core behind the phase angle of the current caused by the conductor as a whole. Starting at 10.5 per cent of the total current at zero frequency, the core current falls to 4 per cent at 10 kilocycles and to 1 per cent at 150 kilocycles. Meanwhile the phase angle of the core current behind the total current increases rapidly from zero to about 40 degrees in the first 10 kilocycles, and then more slowly to 90 degrees in the range from 10 to 150 kilocycles.

For the special conductor studied, the current in the core has a negligible effect upon the current distribution in the copper. Removing the core would cause a discernible change of current density only near the interface and this change is shown by the dashed curve in Figure 6. The difference in the phase change through the copper caused by removing the core is too small to show in Figure 6.

Finally, the total effect of treating the copper-covered steel conductor as a copper tube alone is shown in Figure 2, where the a-c resistance of the tube is referred to the d-c resistance of the composite conductor. Above 10 kilocycles there is less than four per cent difference between the a-c resistances of composite conductor and tube, above 20 kilocycles the approximate treatment is as good as the accurate one.

Thus, for many purposes it may be sufficiently accurate to treat the copper-covered steel conductor as a copper tube at the higher frequencies. The d-c resistance is known, and it should be possible to estimate a transition curve from this value to the curve for the tube with an error of only a few per cent.

Comparison of Several Conductors

Finally, it is of interest to compare the a-c resistances of the bimetallic conductor and the copper tube with that of a solid copper wire of the same outside diameter. This is done in Figure 8, which gives the ratios of the a-c resistances of the respective conductors to the d-c resistance of the copper-covered steel. Thus the ordinates are also proportional to the a-c resistances of the conductors for any common length. At zero frequency the resistance of the solid wire is 42 per cent, that of the tube 111 per cent of the resistance of the copper-covered steel. As the frequency increases, the resistance of the solid wire increases most rapidly, and at 85 kilocycles all conductors have approximately the same a-c resistance. At frequencies above 85 kilocycles the solid wire has the largest resistance as shown on the curve, but at still higher frequencies beyond the range of Figure 8 the curves would again coincide, when the current in all cases would be confined to a thin skin at the outermost boundary. From zero to 85 kilocycles the copper-covered steel has a lower resistance than the copper tube, but, between 85 and 160 kilocycles, the latter frequency being the highest calculated, the copper-

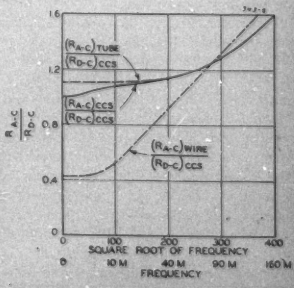

Figure 8. Comparison of a-c resistance of copper wire, copper tube, and copper-covered steel conductor of same outside diameter

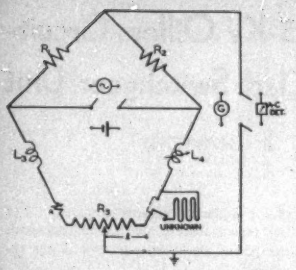

Figure 9. Circuit for measuring resistance ratio

covered steel has a slightly higher resistance than the tube alone.

Appendix A. Derivation of Equations

The current density in each of the regions must satisfy the differential equation

$$\frac{d^2G}{dr^2}+\frac{1}{r}\frac{dG}{dr}-j\frac{\omega\mu}{\rho}G=0 \qquad (3)$$

in which G is a complex number representing the magnitude and phase of the current density at any distance r from the axis. The derivation of the equation may be found in numerous treatments of skin effect, for example, the textbook by Woodruff.[1] The solution must also satisfy the boundary conditions:

1. At $r=0$, G remains finite.
2. At $r=r_1$, ρG is continuous.
3. At $r=r_1$, $(\rho/\mu)(dG/dr)$ is continuous.

The last two conditions come from the field equation

$$\text{Curl } \mathbf{E}=\frac{\partial \mathbf{B}}{\partial t} \qquad (4)$$

which for spatial circular cylindrical symmetry, axially flowing currents, and quantities varying sinusoidally in time reduces to

$$\frac{dE}{dr}=-j\omega B \qquad (5)$$

E being the electric field, and equal to ρG. Thus

$$\frac{d(\rho G)}{dr}=-j\omega B=-j\omega\mu H \qquad (6)$$

Since B is not infinite, ρG must be continuous. On either side of the interface, ρ is constant so

$$\frac{\rho}{\mu}\frac{dG}{dr}=-j\omega H \qquad (7)$$

Although B is not necessarily the same on both sides of the interface, H and ω are the same, hence $\rho/\mu\ dG/dr$ is continuous at the interface.

The solution[8] of equation 3 in each of the regions is

$$G_1=C_1I_0(j^{3/2}ar)+C_2K_0(j^{3/2}ar)$$

$$G_{II}=C_3I_0(j^{3/2}br)+C_4K_0(j^{3/2}br) \qquad (8)$$

in which the C_1, C_2, C_3, and C_4 are constants to be determined, and $I_0(j^{3/2}ar)$, $K_0(j^{3/2}ar)$, and so forth, are modified Bessel functions of the first and second kind respectively.

By the first boundary condition $C_2=0$. The other two conditions permit the evaluation of C_3 and C_4 in terms of C_1 which, since $I_0(0)=1$, is the current density at the center. There results

$$G_1=C_1I_0(j^{3/2}ar) \qquad (9)$$

$$G_{II}=C_1j^{3/2}br_1\frac{\rho_1}{\rho_2}I_0(j^{3/2}ar_1)K_1(j^{3/2}br_1)N(br) \qquad (10)$$

where $N(br)$ has been introduced as the abbreviation

$$N(br)=I_0(j^{3/2}br)+\frac{I_1(j^{3/2}br_1)}{K_1(j^{3/2}br_1)}K_0(j^{3/2}br)+\frac{b\rho_2K_0(j^{3/2}br_1)I_1(j^{3/2}ar_1)}{a\rho_1K_1(j^{3/2}br_1)I_0(j^{3/2}ar_1)}I_0(j^{3/2}br)-\frac{b\rho_2I_1(j^{3/2}ar_1)I_0(j^{3/2}br_1)}{a\rho_1I_0(j^{3/2}ar_1)K_1(j^{3/2}br_1)}K_0(j^{3/2}br) \qquad (11)$$

The current density at the interface is obtained by substitution of r_1 for r in $N(br)$ as it occurs in equations 10 and 11,

$$G_1=C_1j^{3/2}br_1\frac{\rho_1}{\rho_2}I_0(j^{3/2}ar_1)K_1(j^{3/2}br_1)N(br_1) \qquad (12)$$

Similarly, at the outer surface where $r=r_2$

$$G_2=C_1j^{3/2}br_1\frac{\rho_1}{\rho_2}I_0(j^{3/2}ar_1)K_1(j^{3/2}br_1)N(br_2) \qquad (13)$$

The total current is

$$I=2\pi\int_0^{r_1}G_1r_1dr+2\pi\int_{r_1}^{r_2}G_{II}rdr \qquad (14)$$

which, upon substitution of equations 9 and 10, integration, and simplification, gives

$$I=2\pi C_1r_1r_2\frac{\rho_1}{\rho_2}I_0(j^{3/2}ar_1)K_1(j^{3/2}br_1)D(br_2) \qquad (15)$$

where $D(br)$ is the abbreviation

$$D(br)=I_1(j^{3/2}br)-\frac{I_1(j^{3/2}br_1)}{K_1(j^{3/2}br_2)}K_1(j^{3/2}br)+\frac{b\rho_2K_0(j^{3/2}br_1)I_1(j^{3/2}ar_1)}{a\rho_1K_1(j^{3/2}br_1)I_0(j^{3/2}ar_1)}I_1(j^{3/2}br)+\frac{b\rho_2I_1(j^{3/2}ar_1)I_0(j^{3/2}br_1)}{a\rho_1I_0(j^{3/2}ar_1)K_1(j^{3/2}br_1)}K_1(j^{3/2}br) \qquad (16)$$

The constant coefficients of $D(br)$ are the same, except for sign, as the corresponding coefficients of $N(br)$; also in $D(br)$ the variable Bessel functions I_1 and K_1 replace I_0 and K_0, respectively, in $N(br)$. $N(br_2)$ becomes the numerator, and $D(br_2)$ the denominator of the important factor in the expression for the resistance ratio.

In these manipulations the relation

$$I_0(j^{3/2}br)K_0'(j^{3/2}br)-I_0'(j^{3/2}br)K_0(j^{3/2}br)=-\frac{1}{j^{3/2}br} \qquad (17)$$

(in which the prime indicates differentiation of the function with respect to the argument) proves to be useful in reducing the number of terms.

The impedance per-unit length (the reactance originating in that part of the flux only which is interior to the conductor) is the voltage drop per-unit length along the surface b divided by the current[8] or

$$Z_{ac}=\frac{\rho_2G_2}{I}=\frac{j^{3/2}\rho_2b}{2\pi r_2}\frac{N(br_2)}{D(br_2)} \qquad (18)$$

The d-c resistance is the net resistance of core and tube in parallel, and its reciprocal is

$$\frac{1}{R_{dc}}=\frac{\pi r_2^2}{\rho_2}\left[1-\frac{r_1^2}{r_2^2}\left(1-\frac{\rho_2}{\rho_1}\right)\right]=\frac{\pi r_2^2}{\rho_2}P \qquad (19)$$

where P is the per-unit conductivity, the ratio of the conductance of the actual conductor to that of a solid homogeneous conductor of radius r_2 and resistivity of the same length. Thus

$$\frac{Z_{ac}}{R_{dc}}=\frac{j^{3/2}br_2}{2}P\frac{N(br_2)}{D(br_2)} \qquad (20)$$

The Bessel functions used in these equations are given in various forms in different tables.[2, 6, 7] The forms used in the present derivation are related to other forms in Table I. The Jahnke–Emde tables, which give the forms $J_0(j^{3/2}Z)$, $j^{3/2}J_1(j^{3/2}Z)$, $H_0^1(j^{3/2}Z)$, $j^{3/2}H_1^1(j^{3/2}Z)$, were found convenient to use, because both Cartesian and polar forms were given, and because less interpolation was required than in other tables that were available. Equation 1 gives the resistance ratio in terms of these forms.

Appendix B. Experimental Determination of Resistance Ratio

The ratio of a-c to d-c resistance of the specimen of copper-covered steel conductor was measured by means of the bridge circuit shown in Figure 9. The bridge, similar to that used by Kennelly and Affel[9] contains resistance in two arms, and both resistance and inductance in the other two. The bridge is arranged for either alternating or direct current.

R_1 and R_3 are matched resistances of 100 ohms each. L_2 is a toroidal fixed inductance of 35 microhenrys. L_4 is a variable inductor, with a maximum inductance of 36 microhenrys. These inductances are designed to balance the bridge with the unknown in and out of the circuit. The conductor under test has an inductance of 25 microhenrys. R_s is a Manganin slide wire, selected to have negligible skin effect for the range of frequency used, and r is an auxiliary resistance for adjusting the position of the sliding contact on R_s for balance at different frequencies. The conductor tested is switched out of the bridge by a copper bar resting in mercury cups.

The specimen of conductor under test, number 10 American wire gauge copper-covered steel of nominal 40 per cent conductivity, is mounted on an upright wooden frame six by six feet in size. The frame holds 77 feet of wire strung up and down with a spacing six inches between traverses.

The source of alternating current, a laboratory oscillator, is connected through a shielded transformer which serves to isolate

the generator and to match its output to the relatively low impedance of the bridge. The alternating current through the unknown under test conditions varied between 0.04 and 0.16 ampere over the frequency range from zero to 160 kilocycles. The a-c null detector is a General Radio-wave analyzer, the frequency range of which was changed by removing condensers. An external amplifier is used to increase the sensitivity of the detector. For d-c balance a battery and galvanometer are employed. The experimental work was done in a closed room where the temperature was 29 degrees centigrade and remained constant to $^1/_2$ degree centigrade.

Measurements are made in the following manner: with the bridge unbalanced and the unknown in the circuit, a given frequency is applied to the bridge. Then L_1 and the sliding contact of R_s are changed alternately to obtain a closer balance, and the sensitivity of the detector is increased progressively. When both an inductive and a resistive balance are obtained, the setting of the sliding contact on R_s is noted. This is expressed as the distance l_1 of the contact from a reference point. Then this procedure is repeated for the same frequency with the unknown disconnected from the bridge, and the corresponding reading l_2 is noted. The resistance of the unknown at the given frequency is[4]

$$k(l_1 - l_2)$$

where k is a constant which includes the resistance per-unit length of the slide wire. The bridge is balanced immediately then on direct current, and the difference of the two readings is noted. The ratio of the difference of the two a-c readings to the difference of the two d-c readings is the ratio R_{ac}/R_{dc} for the unknown at a given frequency.

Features which tend to minimize errors in the experimental method are:

1. All the components which are varied during a given measurement are placed in the same arm of the bridge. Thus, since each measurement involves a balance, once with the unknown in the circuit and once with the unknown out, the residual errors in the three unaltered arms cancel.

2. Coaxial connections to the various components are used to minimize stray magnetic coupling. Also a coaxial line is used in the detector circuit, for which purpose the single unit containing R_1 and R_2 is mounted on the sliding contact arm of R_s.

3. Components are placed far enough apart to minimize the effects of stray fields.

4. The fixed inductance L_2 and the variable inductance L_1 are made with no metal in their supporting structures. In the variable inductor L_1 litz wire is employed and the shaft, dial assembly, screws, and so forth, are all nonmetallic.

The over-all accuracy of the experimental method was checked by using it to measure the resistance ratio for ordinary copper wire. Values were obtained which agree with the known published values to an accuracy of one tenth of one per cent over the whole range of frequency, and this figure is taken as indicating the order of accuracy of the method.

The results for the copper-covered steel conductor are shown in Figure 2.

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A New 50,000-Kva 5-Kv Oilless Circuit-Breaker and Metal-Clad Switchgear Unit

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50,000-Kva Oilless Circuit Breaker

THE obvious advantages of air circuit breakers have led to their widespread application, particularly in the 2,500- and 5,000-volt class for 100,000- and 150,000-kva interrupting rating. This has in turn brought a demand for lower kilovolt-ampere ratings in these voltage classes. In the past the oil circuit breaker has been the only device economically applicable in this particular field. However, progress in design and manufacturing facilities has made it possible to build a 50,000-kva unit lower in cost than would have been considered feasible two years ago and one which is expected to meet the operating requirements in this field.

The interrupter is of the magnetic De-ion type and is illustrated schematically in Figure 1. Briefly, the theory of operation of this type of breaker embodies the use of spaced insulating plates of nongas-forming material having tapered slots into which the arc is moved by a magnetic field. As the arc moves into the narrow portion of the slot, electrons in the arc stream, attaining a high velocity from the magnetic field, bombard the gas particles of the arc stream and require the arc continuously to ionize fresh gas in considerable quantities. When current zero is reached, this action continues sufficiently to deionize the plurality of short lengths of arc near the edges of the plates, thereby establishing sufficient dielectric strength to interrupt the circuit.

In the design of the 50,000-kva breaker the insulating plates are made of a high heat-shock resisting material as in previous designs.[1,2] On account of the lower short-circuit currents for this rating, it was possible to reduce the thickness and width of these plates to two-thirds that of the higher interrupting ratings. For this reason also it was possible to space the plates about 30 per cent closer together.

In order further to reduce the size of the arc chute, the number of plates was reduced. The required volts-per-plate interrupting ability was then obtained by increasing the magnetic field. In doing this, the number of turns on the blow-in coil was increased from 6 to 18. This gave a considerable increase in the magnetic field which in turn increased the voltage per plate.

This combination of design features sufficiently reduced the size of the arc chamber to permit the over-all breaker design to be comparable in size with the corresponding oil breaker.

Figure 2 illustrates the breaker as built for metal-clad use. It will be noted that the contacts represent a departure from previous practice on small air circuit breakers in that they are of the parallel blade type, resembling disconnecting switch construction. The hinged joint at the bottom of the blades is of the spring-pressure type with silver surfaces.

The main contact surfaces of the blades are of a type previously developed for disconnecting switches and have proved very reliable in that service. The main contact surfaces are integral with the blades, and hence joints between these parts are eliminated.

The movable contact blades are operated through a simple linkage by a

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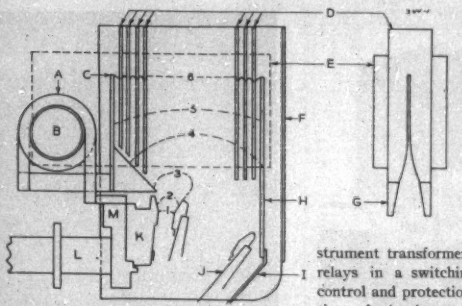


Figure 1. Schematic illustration of typical magnetic De-ion interrupter

The dotted lines 1, 2, 3, 4, 5, and 6 indicate progressive positions of arc interruption

A—Magnet coil
B—Iron yoke
C—Panel-end horn
D—Insulation plates
E—Laminated iron shoes
F—Outline of arc chamber
G—Arc shield
H—Arcing horn
I—Shunt strap
J—Moving contact arm and arcing contact
K—Arcing and secondary-contact platform
L—Micarta bushing
M—Upper stud

mechanically trip-free solenoid mechanism previously applied to oil breakers. Thus, the control circuits may follow established practice in all respects.

The unit illustrated in Figure 2A and 2B is designed to be rolled into the operating and test positions on wheels located on the main frame of the breaker only a few inches below the disconnecting contacts. This gives a close mechanical relationship between the disconnecting contact load, the drive-in force, and the load on the rails.

Tests

In line with modern switchgear-design practice where high-power laboratory facilities are available, numerous interrupting tests were made in the development of the breaker. Table I shows representative results of a typical series of three-phase tests on the breaker in its final form. It will be noted that the maximum kilovolt-amperes interrupted is approximately 60,000 at 4,800 volts, three phase. Figure 3 shows a typical oscillogram taken at 7,300 amperes and 4,800 volts, three phase.

The interruption of low currents at low power factor, corresponding to magnetizing currents, was investigated. The arcing time of the breaker extends to approximately 30 cycles on account of the low magnetic forces for moving the arc from the contacts into the arc chute. Since the arc chute is mounted directly above the breaker contacts, convection air currents assist in moving the arc, and this results in positive and consistent operation. Figure 4 shows a typical oscillogram taken at 20 amperes and 4,100 volts on a single pole.

Metal-Clad Switchgear Unit

To utilize the new 50,000-kva oilless breaker, a new horizontal drawout metal-clad switchgear unit has been designed. It incorporates the associated bus, instrument transformers, instruments, and relays in a switching structure for the control and protection of power distribution of circuits and associated electric apparatus. Figure 6 shows the air-breaker unit on the transfer truck in position to be placed in the housing.

Design Specification

In designing such a unit the following essential requirements had to be met:

(*a*). Compact design, still retaining best performance of circuit breaker under normal current-carrying and interrupting duty and mounting security.

(*b*). Safety and convenience in installation and operation.

(*c*). Accessibility for maintenance.

(*d*). Simplicity and minimum cost.

The metal-clad structure design should be such as not to reduce the effectiveness of the circuit breaker as measured by its performance unenclosed. To accomplish this, clearances and ventilation must be adequate and the arc gases freely vented. The mounting for the circuit breaker must secure it accurately and rigidly in its operating position to insure correct alignment of disconnecting devices and to prevent undue vibration and movement in service.

The horizontal drawout mounting is particularly adapted to air circuit breakers, since it permits a horizontal contact break and utilizes the definite tendency of the arc to rise and thus move naturally into the deionizing chamber. It also gives more ready accessibility to the breaker to permit quick superficial inspection.

All live parts should be enclosed in

Table I. Interrupting Tests on 50,000-Kva Air Breaker

Test Voltage	Current Interrupted			Average	Megavolt-Amperes	Operation
	Phase 1	Phase 2	Phase 3			
4,800	6,000	7,900	8,100	7,300	60.8	*O*
4,800	6,600	7,900	7,200	7,200	60.0	*O*
4,800	6,700	7,700	6,700	7,000	58.2	*O*
4,800	6,900	7,700	9,700	8,100	58.2	*CO*
4,150	8,600	6,800	6,800	7,400	53.2	*CO*
4,160	6,200	7,700	7,900	7,300	60.8	*CO*
4,800	7,900	5,800	6,800	6,800	56.6	*CO*
4,800	6,000	6,200	7,900	6,700	55.8	*CO*
4,700	2,400	1,700	1,900	2,000	16.6	*CO*
4,800	2,100	1,700	1,800	1,900	15.8	*CO*
4,800	490	430	580	470	3.9	*CO*
4,800	540	360	480	460	3.8	*CO*
4,800	1,030	1,010	970	1,000	8.3	*CO*
4,800	2,000	2,200	2,200	2,100	17.5	*CO*
2,200	17,400	12,600	18,700	16,200	61.8	*CO*
2,200	18,500	13,100	15,500	15,700	60.0	*CO*
2,200	16,200	12,100	17,300	15,200	58.0	*CO*
2,200	16,200	12,600	17,300	15,400	58.8	*CO*
2,200	17,400	14,400	14,100	15,300	58.2	*CO*
5,000	4,700	5,100	4,700	4,800	41.6	*CO*
5,000	5,200	3,800	5,300	4,800	41.6	*CO*

O—Open.
CO—Close-open.

Table II. Interrupting Tests on 50,000-Kva Breaker Assembled in Metal-Clad Switchgear Unit

Test Voltage	Current Interrupted			Average	Megavolt-Amperes	Operation
	Phase 1	Phase 2	Phase 3			
5,000	5,515	5,890	6,495	5,967	51.6	*CO*
5,000	5,990	6,240	6,940	6,217	53.9	*CO*
5,000	5,890	6,450	7,710	6,683	57.8	*CO*
5,000	7,530	5,760	5,850	6,380	55.2	*CO*
5,000	7,550	5,690	7,200	6,880	59.5	*CO*

CO—Close-open.

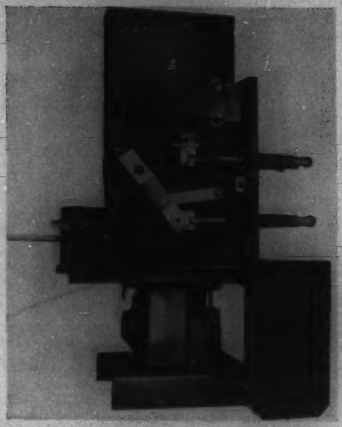


Figure 2A. Removable breaker for 600-ampere 5,000-volt 50,000-kva metal-clad switchgear unit

One arc chute shown removed at the lower right

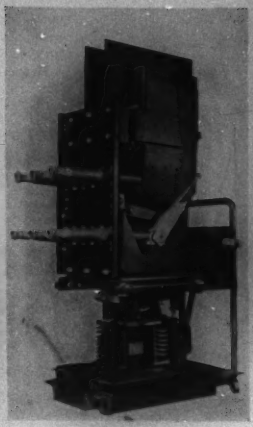


Figure 2B. Rear view of removable air-circuit-breaker unit

Figure 3. Oscillogram showing interruption of 7,300 amperes at 4,800 volts, three phase, 60 cycles on the 50,000-kva oilless circuit breaker

A—Voltage, phase 3
B—Current, phase 3
C—Voltage, phase 2
D—Current, phase 2
E—Voltage, phase 1
F—Current, phase 1

grounded metal compartments, and covers should be provided to give access to each portion of the circuit separately, without exposing any other circuit. The structure must be built ruggedly to withstand shipping stresses and to permit handling as a complete assembly without causing misalignment, so that it can be shipped in as large unit groups as possible.

Operation should be simple, since the application for this size breaker is quite largely in small stations where highly trained personnel is not available.

General Description of Metal-Clad Unit

The steel housing consists of a welded structural frame with sheet-steel barriers dividing the unit into three principal high-voltage compartments for the bus, circuit breaker, and current transformers, together with the main cable terminals. The complete units are separated from each other by sheet-steel barriers, and the bus opening through this barrier is entirely covered by the Micarta insulating support in order to divide the bus compartment into unit lengths.

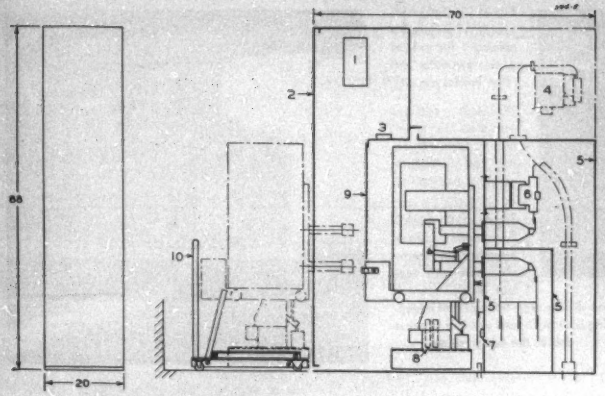
The busses and connections are insulated completely with Micarta and varnished cambric as shown in Figure 7. The main bus joints are insulated with molded enclosures, which are clamped over the joint by means of tapered keys, and are filled with insulating compound to seal the joints and make the bus insulation continuous. All joints in busses and connections are silver-surfaced to maintain permanently high conductivity.

The highly important primary disconnecting devices consist of flexible finger assemblies mounted directly on the ends of the removable breaker-unit bushings and cylindrical studs mounted in insulating tubes in the housing to provide insulation between phases and to shield them from accidental contact, as Figure 8 shows. The flexible finger assembly consists of bridging segments which make point contacts on the breaker bushing at one end and on the cell stud at the other end, when in the engaged position. A new form of segment is used which is profiled, so that each segment makes two points of contact at each end to reduce millivolt drop. High unit pressure is obtained by flat springs located between an encircling ring and the contact segments in order to exert radial pressure inward on each segment. It will be noted that since each spring exerts radial pressure on its own segment independently of the others, the contact pressure exerted is independent of the number of segments used, so that various contact capacities can be obtained by using different multiples of the same segments and springs. Contact surfaces are heavily silver-plated to insure permanently low resistance.

The hinged panels on the front provide space for mounting instruments, relays, control switches, and other panel devices to form a completely self-contained switching unit as shown in Figure 9. The control and secondary circuits are completed to the breaker unit by means of a multipoint plug and receptacle-type contact. Figure 10 shows the plug assembly on the breaker unit mounted on a novel sliding member with sufficient travel to permit re-engaging it for test when the breaker unit is moved to the test position with the main contacts disengaged. The contacts engage automatically in the operating position, and the sliding mounting is latched, so that they disengage

Figure 4. Oscillograms showing typical low-current low-power-factor interruption

Current 20 amperes at 4,100 volts across a single pole



A. Front view B. Sectional side view

Figure 5 (above). Outline of metalclad unit

Front view and section drawing showing isolation between high-voltage compartments of housing

1. Control panel
2. Hinged door (instrument panel)
3. Cross wiring
4. Potential transformer
5. Removable cover
6. Current transformer
7. Terminal block
8. Secondary contact
9. Hinged barrier
10. Transfer truck

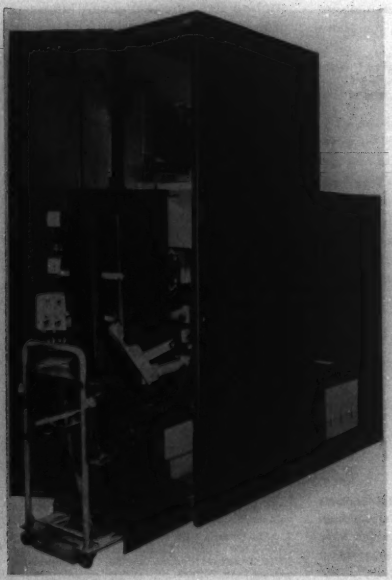


Figure 6 (left). Metal-clad switchgear housing with air circuit breaker on transfer truck in position to enter

Lever operated elevating device of transfer truck permits lowering unit to floor or picking up

normally when the unit is withdrawn to the test position.

The removable unit, comprising the circuit breaker and its frame support, is carried on flanged rollers which engage the track in the housing. It is transported and placed in position by means of an auxiliary transfer truck equipped with a simple lever-type elevator of limited movement, which will raise the unit from the floor and lower it to position on the housing rails. From this

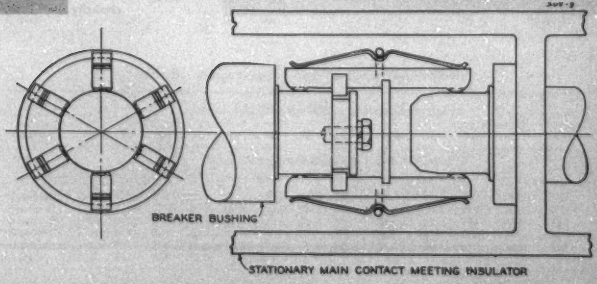
Figure 7. Insulated bus and connections assembly

point, a single rugged worm-and-gear levering device is used to move the breaker unit into and out of the operating position. The worm mechanism is self-locking and holds the removable unit securely in the operating position. A notched cam on the levering-device shaft prevents moving the breaker into or out of engagement with the disconnecting contacts, unless the breaker is in the open position, and permits breaker operation only in the operating and test positions. (See Figure 11.)

Tests on Assembled Switchgear

Supplementing the detail tests made on the separate circuit breaker, tests were made in the metal-clad housing at maximum interrupting rating. In addition, a series of repetitive moderate interrupting-duty tests was made to simulate typical motor-inching duty where starting current is opened and closed several times in rapid succession. High-current tests were made as shown in Table II. Twenty-five close–open tests with nine-second intervals were

Figure 8. Details of primary disconnecting contact showing both stationary and moving members



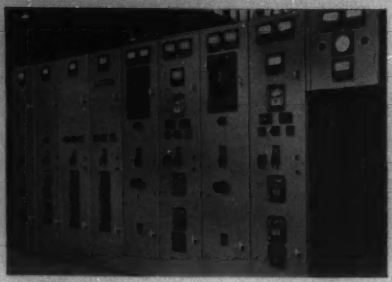


Figure 9 (left). A typical metal-clad assembly for control of two generator and four feeder circuits

Auxiliary sections are used to mount the voltage regulator and excitation control equipment

Figure 10 (right). Secondary contact assembly on removable unit with contact block mounted on sliding support to permit engaging control circuits with the breaker unit in the test position

made at approximately 1,500 amperes to simulate repetitive duty on typical motor-starting inrush current. These tests were made too rapidly to permit taking oscillographic records of current.

Careful examination and inspection during and after the tests showed that the enclosing housing has adequate clearance and ventilation to insure the best performance of the circuit breaker and that the connection and bus structures and breaker support are entirely adequate. Figure 11 shows the condition of the breaker contacts after the series of tests.

In addition, momentary current tests at the maximum short-time rating of 25,000 amperes were made on the assembled structure and circuit breaker to prove that the mechanical and thermal capacity was adequate. Dielectric tests at 19 kv, 60 cycles for one minute and 60 kv impulse were made in accordance with the proposed insulation levels for this class of equipment.

Figure 11. Breaker contacts after series of 73 close–open operations, 26 of which were at or above rated interrupting capacity

Conclusion

Extensive development work and careful cost-analysis work on the larger sizes of air circuit breakers have made it possible to produce a 50,000-kva unit comparable in size, weight, and use of critical material with the corresponding oil-circuit-breaker unit. This makes the obvious advantages in maintenance, safety, and convenience of air-type interrupting devices available for applications to smaller generating and distribution stations, industrial plants, and unit substations.

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Factors Affecting the Design of D-C Magnets

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Synopsis: This paper outlines some of the factors which should be considered in the design of d-c magnets. The usual types of steel used are briefly discussed, including their influence on "sticking" or residual forces. Calculated curves are presented which show the influence of pole-face area on the force developed by the magnet. Flux measurements on a number of magnets show that theoretical calculations are often in great error because of factors such as leakage and saturation which are usually neglected. Data show that the flux in a d-c magnet with a small air gap may vary by as much as 300 per cent between one part of the circuit and another.

D-C magnet design is of tremendous importance today because of the almost exclusive use of d-c power in mobile equipment such as tanks and airplanes. Magnets are the backbone of the d-c control systems, for, when energized by push buttons or interlocks, they furnish the power to operate contactors and relays of all descriptions or to perform strictly mechanical functions, such as actuating firing pins or locking devices. With applications such as these, new requirements have arisen. Chief of these are light weight, minimum volume, insensitivity to vibration with the magnet open or closed, and higher operating temperatures.

Although d-c magnet design is an old subject, there appears to be very little literature on it which is of help to the designer. Text books[1] give an adequate presentation of theoretical principles involved, but assumptions which must be made to solve a problem theoretically are more often than not the dominant considerations in practical design. The tremendous diversity of design requirements has led to a large number of different forms of magnets dictated by device operation and requirements. It is impossible to find a design procedure suitable for all cases, but the same factors, such as saturation, leakage, residual forces, and kind of steel, must be considered in each. Of these, leakage appears to bear an importance not previously suspected. Flux measurements have been taken on a large number of magnets to show their magnitude. The results of some of these measurements are discussed.

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Steels

At present, the four general kinds of steel which are considered for use in the usual design of d-c magnets are:

1. Cold rolled or stamping steel.
2. Silicon steel.
3. Low metalloid steel or ingot iron.
4. High-saturation steel such as 50 per cent cobalt, 50 per cent iron.

Tables I and II list the magnetic properties of these steels. The term, "aging factor," which appears in Table I is defined as the per cent increase in hysteresis loss which occurs to a steel with time. As applied to d-c magnet design, an increase in the hysteresis-loop area is significant principally in the second quadrant, where an increased area means an increase in external energy and in coercive force. An accepted laboratory method of finding the aging factor is to measure the d-c hysteresis loop before and after holding the steel at 100 degrees centigrade for 600 hours.

Common stamping steel is the most widely used for d-c magnets because of its low cost and its desirable mechanical qualities. It is readily drawn, punched, or formed, and is available in a large variety of forms and sizes. Its main disadvantage is that it is not sold as a magnetic steel; the mills do not guarantee magnetic qualities. Large variations, therefore, can and do occur in the magnetic quality of this steel. In general, in the annealed condition, it has a better magnetization curve for the higher densities and a higher saturation value than the silicon steels. However, its coercive force is high; its available external energy is high, and its aging factor is large. A design using this material must be checked carefully, not only for residual forces which exist at the time of manufacture, but also for increased forces which may develop because of aging.

As the percentage of silicon in steel increases, the saturation curve becomes poorer, and the intrinsic saturation falls. The silicon steels are also harder to fabricate. These disadvantages are offset by the fact that these steels are sold with specified magnetic properties and are of consistent quality. As the silicon content increases, the aging factor decreases, the largest aging factor for a silicon steel being considerably less than for common stamping steel. The coercive force and external energy are likewise considerably less.

Ingot or Armco iron is the purest form of iron sold commercially. When properly

Table I. Magnetic Properties of D-C Magnet Steels

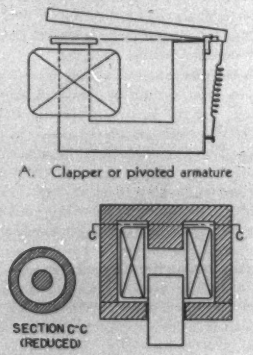
Kind of Steel	Alloying Constituent (Per Cent)	Intrinsic Saturation (Kilolines Per Square Inch)	Aging Factor (Per Cent)	Residual Induction (Kilogausses)	Coercive Force (Oersteds)	External Energy (Maximum)
Common	0.25 silicon maximum	133	15	7.9	1.5	4,650
Silicon *A*	0.25-0.75 silicon	132.3	8	8.37	0.85	3,450
Silicon *B*	0.75-1.25 silicon	131.5	5	8.0	0.70	2,400
Silicon *C*	2.50-3.0 silicon	126	3	8.1	0.67	2,450
Ingot iron	None	131.5	Varies	7.5	1.05	2,330
Cobalt	50 cobalt	148		10.5	3.5	25,800

Table II. Magnetization Data for D-C Magnet Steels

Kind of Steel	Total Flux Density (Kilolines Per Square Inch)												
	10	30	50	70	80	85	90	95	100	105	110	115	120
	Magnetizing Force (Ampere Turns Per Inch)												
Common	1.98	3.55	5.1	8.1	11.1	14.1	19.2	28	45	77	136	235	355
Silicon *A*	1.17	2.05	3.35	6.2	10.3	14.8	22.5	38	66	120	192	290	420
Silicon *B*	1.20	2.05	3.3	6.4	10.9	15.0	22.5	39	69	120	195	300	430
Silicon *C*	1.10	1.79	3.1	6.4	11.8	18.5	34	65	116	187	280	410	570
Ingot iron	1.2	2.3	3.5	5.2	6.6	7.5	8.9	12.0	21.5	55	116	165	257
Cobalt	2.0	4.4	5.3	6.0	6.8	6.6	6.9	7.4	8.1	9.0	10.5	12.5	15.8

annealed, it has the best magnetization curve and the highest intrinsic saturation value of the usual steels. It is ductile and tough, but readily forged, machined, or welded. Its external energy curve is low. Its magnetic qualities tend to be influenced considerably by the type of anneal which it receives. Its main disadvantages are its relatively high cost and lack of availability in various forms and sizes.

The use of special high-saturation steels is not so widespread as might be supposed, because of the relative difficulty of obtaining them, together with their high cost, poor machining properties, and high coercive force and residual induction. However, as Tables I and II show, a 50 per cent cobalt, 50 per cent iron has a remarkably good induction curve and high intrinsic saturation.



A. Clapper or pivoted armature

B. Solenoid

Figure 1. Types of d-c magnets

In all d-c designs, especially in those using stamping steel, it is essential for consistent performance that an air gap be in the circuit between the armature and pole face. The order of magnitude of residual forces is often underestimated. In one case a magnetic circuit of ingot iron weighing five pounds two ounces was found to have 33 pounds residual force when there was no air gap in the circuit. In another case a small relay using annealed stamping steel weighing 32 grams had a measured residual force of 112 grams. When a magnet operates, the repetitive shock of one part on another, together with the simultaneous application of magnetic field, tends to increase the coercive force. It has been found in practice that this increase may be considerably more than the aging factor would indicate.

Classification of D-C Magnets

D-c magnets can be classified into two general groups:

1. Clapper or pivoted armature type.
2. Solenoid or pot type.

A typical form of clapper magnet is shown in Figure 1A. An armature is pivoted on one face of a U-shaped piece and rotates through an air gap to strike a pole face. The coil may be placed on any leg of the core. In Figure 1B is shown a solenoid-type magnet in which a plunger, usually circular, moves within a coil to strike a core or head finally.

Design requirements for a magnet are usually:

1. It should give a force-versus-stroke curve suitable for the particular requirement.
2. It should utilize to the fullest extent every ounce of iron and copper in the magnet.
3. It always should release under the action of the restoring spring when de-energized.

These requirements determine whether a clapper or solenoid magnet will be used. The shape of the pull curve of a clapper magnet can be changed by varying the pole-face area; that of a solenoid type by using some variation of a stepped plunger or conical plunger.

Force Formula

In order to find the flux in a circuit consisting of an iron path in series with a short air gap, a trial-and-error method is usually employed. A value of flux is assumed; the various magnetomotive-force drops are found, and their total compared to the applied magnetomotive force. A result sufficiently accurate can be obtained usually in two or three trials. When the flux is found, the force between faces is obtained from

$$F = \frac{B^2 A}{8\pi} \tag{1}$$

where F is the force in dynes, B the air gap flux-density in gausses, and A the area in square centimeters. This formula is the one occurring most frequently in texts and is apt to be misleading when the assumptions on which it is based are neglected. When saturation in the iron is negligible, equation 1 reduces to

$$F = \frac{B^2 A^2}{8\pi A} = \frac{\phi^2}{8\pi A} = \frac{(0.4\pi NI)^2 A}{L^2} \tag{2}$$

where ϕ is the total flux crossing the air gap, NI the ampere turns applied to the circuit, and L the length of the air-gap centimeters.

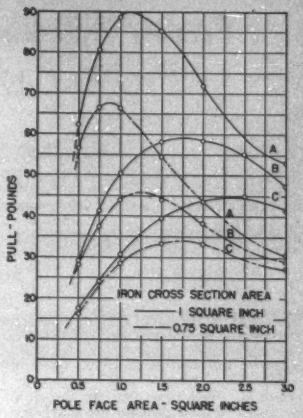


Figure 2. Effect of pole-face area on pull for various air gaps

A. 0.060-inch gap
B. 0.090-inch gap
C. 0.120-inch gap

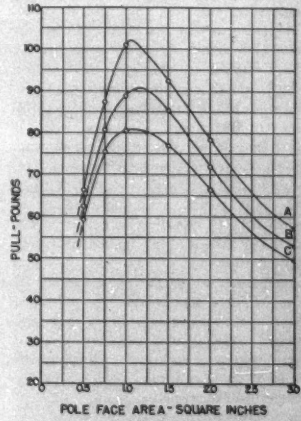


Figure 3. Effect of pole-face area on pull for various lengths of magnetic paths

A. 7.5 inches
B. 10.0 inches
C. 12.5 inches

Equation 2 is a much more accurate form to use when drawing conclusions of the effect on the force of changing physical dimensions. This equation states that if there is no magnetomotive-force drop in the iron, the force varies directly as the face area, directly as the magnetomotive force squared, and inversely as the air gap squared.

Optimum Pole-Face Area

It is seldom economical to operate a magnet so low in flux density that the magnetomotive-force drop in the iron can be neglected. In general, then, when saturation is taken into account, it is possible to show analytically that there is a pole-face area which will give the maximum pull for any one particular set of conditions. The method involves finding a suitable expression for the B, H curve, solving for B in the particular circuit, and then substituting for B^2 in the force equation. This equation may be differentiated then with respect to the pole-face area to find the area for maximum pull. This method is long and tedious. It is faster and more accurate, as soon as a little experience has been gained, to solve a circuit by a trial-and-error method, using the saturation curve of the steel involved. To illustrate the results obtained by this latter method, the following example was worked out: A magnetic circuit was assumed to consist of a ten-inch iron path in series with an air gap of 0.060 inch, 0.090 inch, and 0.120 inch with 2,000 ampere turns applied to the circuit. Two assumptions were made:

1. The ampere turns per inch of iron circuit were constant.
2. There was no fringing in the air gap.

In view of data which are presented later, it will be seen that these two assumptions introduce large errors. They are, however, necessary for a theoretical solution which must be arrived at without the aid of any experimental data. Figure 2 shows the results obtained. It should be noted that the area for maximum pull varies for different air gaps. This point is of great importance for it means that each magnet design can be shaped for a particular requirement.

In the operation of d-c contactors it is a desirable characteristic to have the forces such that the armature will not hesitate when the contact tips first touch. By using the proper core head, the force generated can be kept low in the fully open position and made a maximum at the point where the contact forces begin, so that, when the armature once starts to move, it carries the tips through their kiss-and-wipe position without hesitation. Figure 3 shows the result of varying the length of iron path for the case when the iron cross section is one square inch, the applied ampere turns 2,000, and the air gap 0.060 inch. Figure 4 shows the effect of impressing various magnetomotive forces on a magnetic circuit of ten-inch iron length, 0.60-inch air gap, and one square inch cross section. As the applied magnetomotive force is increased, the pole-face area for maximum pull decreases.

In certain devices such as telephone relays, where the flux density is often very low, the pull of a magnet follows equation 2. The size of the head or pole face can then be increased until the leakage, which is introduced because of the larger head, becomes a limiting factor. An example of this case using an equivalent electric-circuit analogy is treated in the literature.[2]

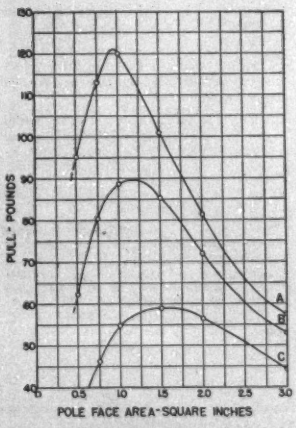


Figure 4. Effect of pole-face area on pull for various impressed magnetomotive forces

A. 2,500 ampere turns
B. 2,000 ampere turns
C. 1,500 ampere turns

Air-Gap and Leakage Flux—Experimental Data

Figure 5 shows a type of clapper magnet whose proportions are to scale, which was investigated to obtain data on the distribution of flux in the circuit. Search coils consisting of five turns of 0.005*E* wire were wound on the frame and armature as shown at positions *a*, *b*, *c*, and *d*. The coil at *b* was wound very carefully as close to the air gap as possible and gave flux values which were taken as the air-gap flux. Data were taken on three such magnets, of the same proportions but of different sizes, which weighed about 8, 12, and 20 ounces. Various ampere turns were applied to the main coil; the flux in each of the search coils was then read for various air gaps. All flux data were taken in an engineering laboratory with a ballistic galvanometer. Using the measured values of density, the magnetomotive-force drop in the iron was found and subtracted from the applied magnetomotive force. The net magnetomotive force was used to calculate the flux which should cross the air gap, assuming no fringing.

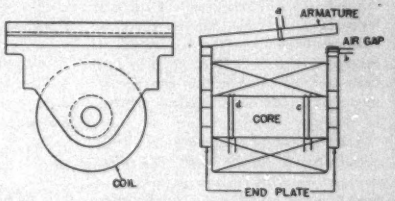


Figure 5. Form of d-c magnet used in studying flux variations

The results obtained are shown in Figure 6 where *A*, *B*, and *C* represent the three different sizes of magnet. It should be noted that the equivalent fringing factor which may be taken as the ratio of measured-to-calculated flux is not constant but decreases with increasing density—probably because of local saturation at the edges of the pole face. For magnets *A* and *B* the pole-face thickness, which, as shown on Figure 5, is the end-

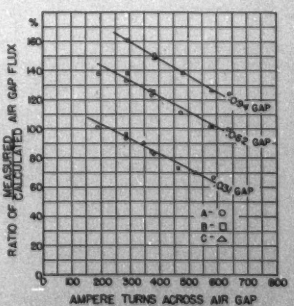


Figure 6. Ratio of measured to calculated air-gap flux for various impressed magnetomotive forces

plate thickness, was 0.094 inch. For magnet *C* the thickness was 0.125 inch. Because of the limited amount of data taken so far on this type of structure, no attempt has been made to determine fringing coefficients as a function of the air-gap dimensions. Figure 5, however, shows clearly the great error which would result if the air-gap flux is calculated on the basis of no fringing, even for the case where the separation is only 33 per cent of the pole-face thickness.

Table III shows the ratio of the total measured flux in the core (the average of search coils *c* and *d*) to the total measured flux in the air gap. In these three magnets the core was about 25 per cent larger in cross section than the rest of the magnetic circuit, but the density due to leakage is seen to be very much greater than this increased section can accommodate without excessive magnetomotive-force drop.

That these large leakage factors are not peculiar to the type of magnet illustrated in Figure 5 is shown from data which have been taken on other types. Readings obtained on a magnet similar to Figure 1A, except with a long thin coil and smaller separation between the legs of the core, showed a ratio of flux measured at the center of the coil to flux measured at the pole face of 250 per cent to 333 per cent over the operating gaps of the magnet. In a solenoid-type magnet, such as Figure 1B, the ratio of maximum flux in the circuit to the useful flux crossing the air gap was found to be 150 per cent.

These leakage figures, of course, vary with the dimensions employed. No attempt here is being made to compare the leakages for various constructions. The only fact which is being presented is that leakage flux in d-c magnetic devices is of an order of magnitude which makes it necessary that their effect be considered in the design. The often seen assumption, "neglect leakage," made in order to effect an analytical solution cannot be justified in many cases.

Table III. Ratio of Core Flux to Air-Gap Flux for D-C Magnets

	Magnet A	Magnet B	Magnet C
	Impressed Ampere Turns		
	300	400	500
Air-Gap Length in Inches	Core Flux / Air-Gap Flux in Per Cent		
0.031	190	183	166
0.062	236	224	200
0.094		253	225
0.253			306

Conclusions

In addition to data presented here, extensive tests have been conducted on many types of d-c magnets from which the following conclusions may be drawn.

1. Residual forces in magnets may be very large. In a circuit without an air gap, these forces are dependent on the residual induction rather than on the coercive force. Since magnetic steels do not vary greatly in residual induction, an air gap must be in the magnetic circuit of even a low coercive-force material.

2. There is a best pole-face area for maximum pull. This area varies with the air gap and applied ampere turns.

3. Conventional methods of calculating flux in a magnetic circuit are likely to lead to large errors because of the lack of leakage coefficients in calculating air-gap flux.

4. The flux density in a conventional magnet with a small air gap may vary by as much as 300 per cent between one part of the circuit and another.

5. A ballistic galvanometer is a very useful tool in d-c design because of its accuracy and ease of use.

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1. Principles of Direct-Current Machines (book). A. E. Langsdorf. McGraw-Hill Book Company, Inc., New York, N. Y., 1940.

2. A Method of Designing an Efficient Ironclad Electromagnet. H. N. Wagar. Bell Telephone System monograph 508, 1930.

3. Electromagnetic Devices (book). H. C. Roters. John Wiley and Sons, Inc., New York, N. Y., 1941.

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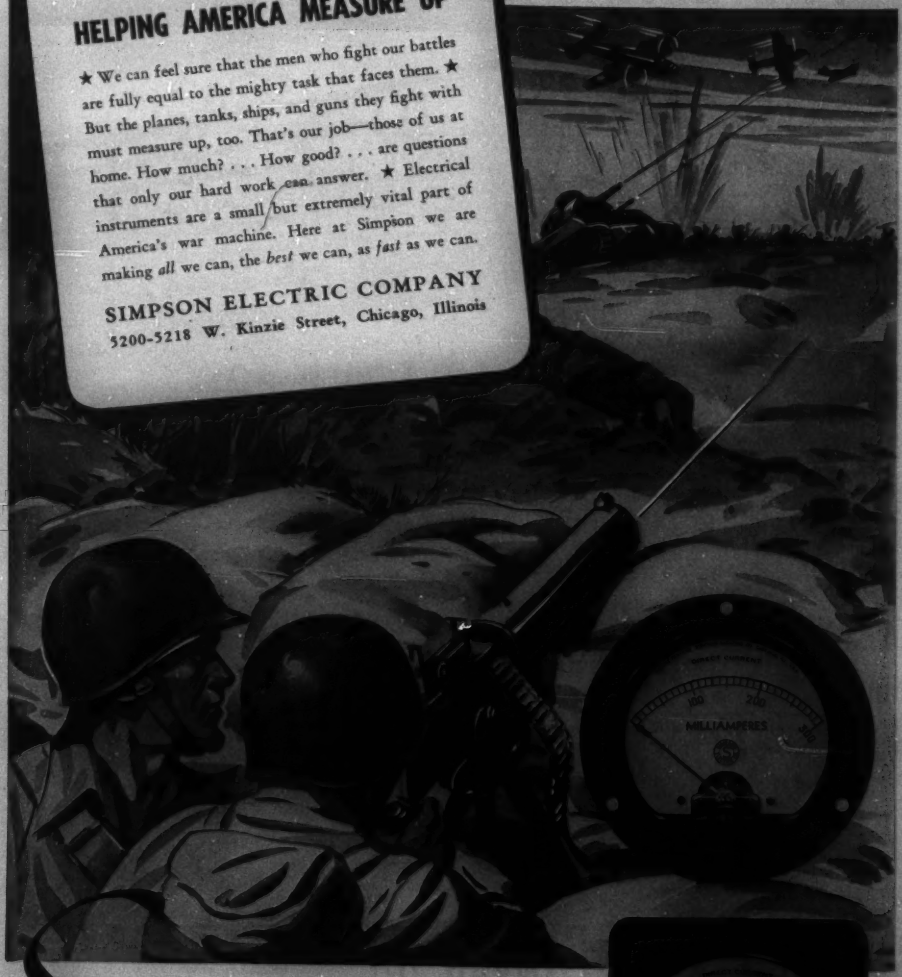

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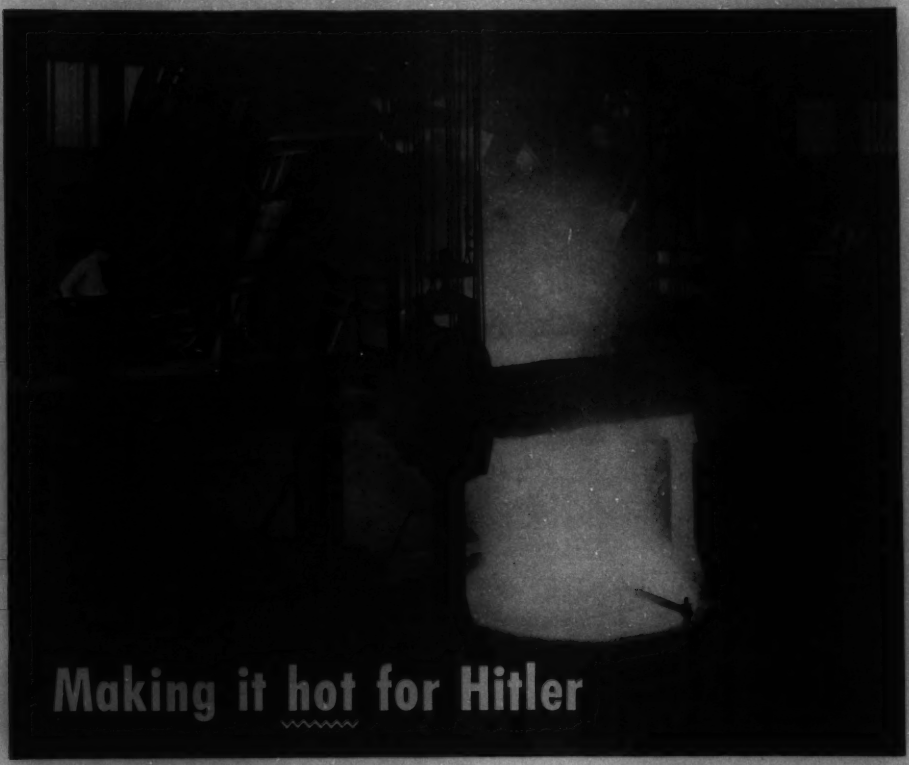

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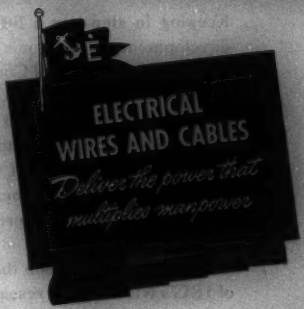

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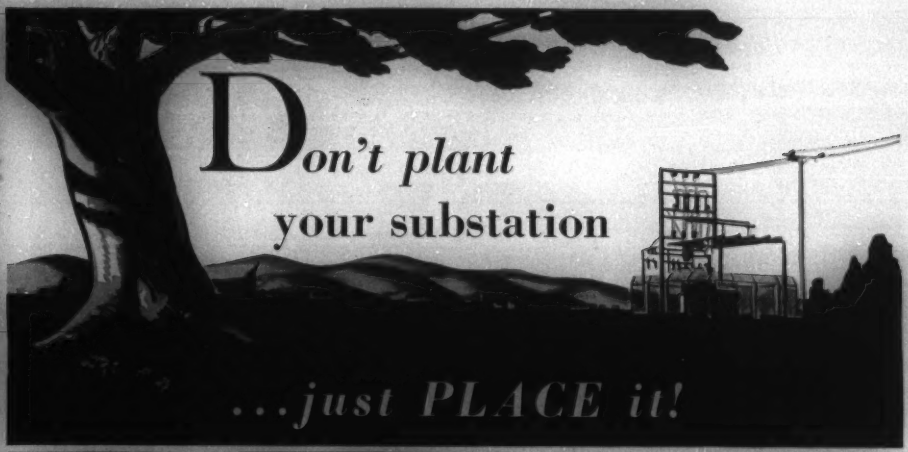

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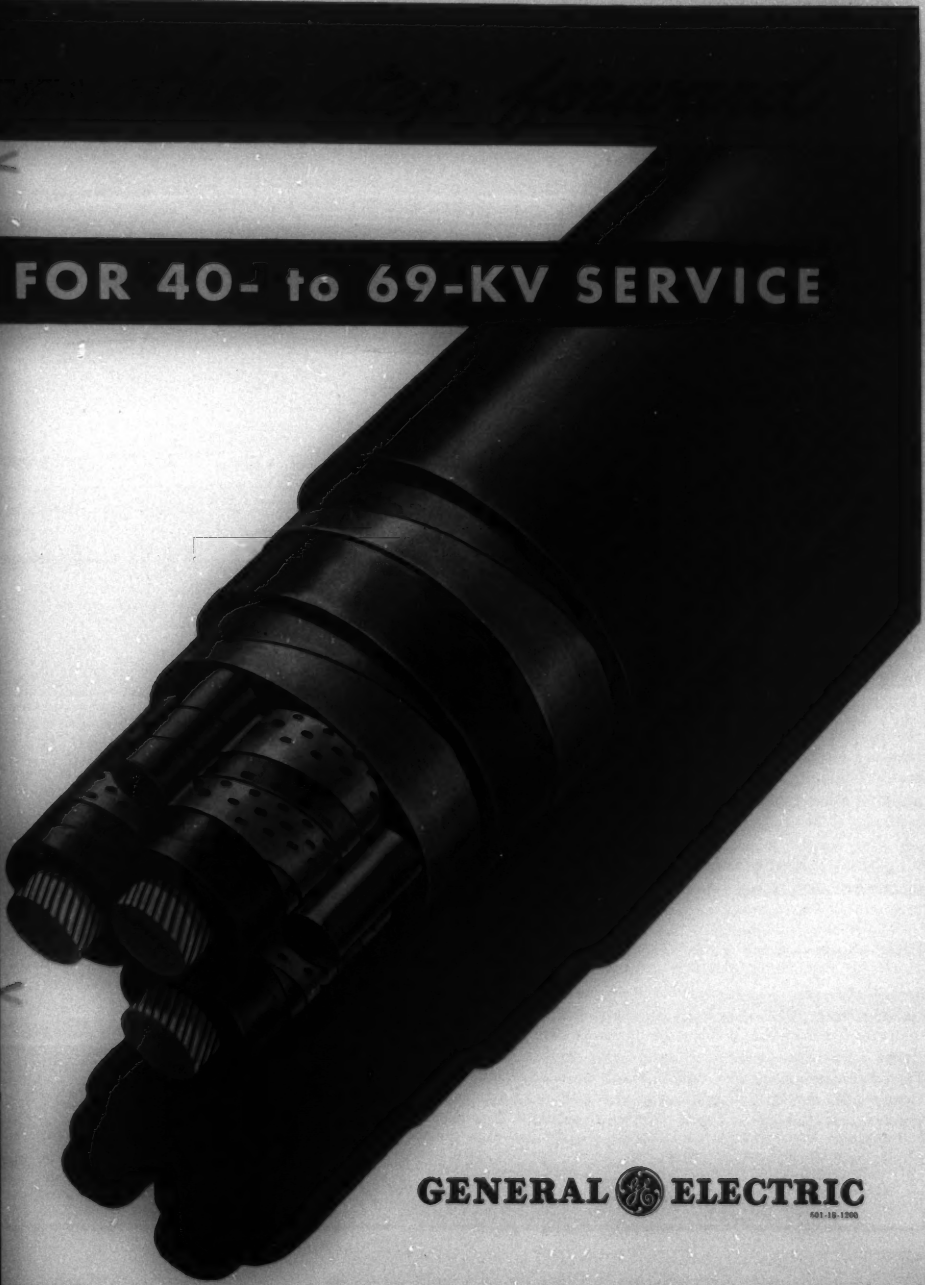

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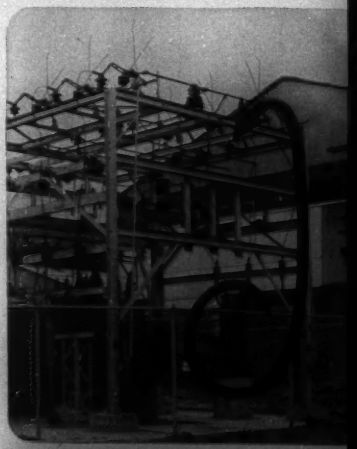

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***PYRANOL OR OIL-FILLED**—For the best protection to your system, you'll want to specify Pyranol—General Electric's non-inflammable cooling and insulating liquid. It has high dielectric strength and is chemically stable.

*Reg. U. S. Pat. Off.

The Army-Navy "E", for Excellence in the manufacture of war equipment, now flies over six G-E plants employing 100,000 men and women.

GENERAL ELECTRIC

QUALITY CONTROL

in the GENERAL RADIO Standardizing Laboratory

HOWEVER well designed an instrument may be, accurate calibration and reliability in service determine its ultimate usefulness. Testing, therefore, has long been an important final step of our manufacturing; approximately 10% of the total man hours required to produce a General Radio instrument is spent in our standardizing laboratory. Here a carefully planned schedule of tests and measurements transforms an unadjusted, uncalibrated device into a precision instrument.

Testing specifications embody not only the rigid requirements imposed by the design objectives of the instrument, but also the field data collected in hundreds of case histories of similar instruments. Engineering test and calibration operations cover far more than meter reading and embrace a wide variety of precise electrical measurements.

To carry out these tests, capable personnel, adequate test equipment, and reliable standards are necessary. Many of the staff have engineering degrees or are graduates of engineering institutions. All are capable technicians. The laboratory equipment includes the entire line of General Radio instruments as well as those of many instrument manufacturers in other fields. As a basis for the measurements, the laboratory maintains precise, accurately-known standards of resistance, capacitance, inductance and voltage. Frequency measurements are based on the engineering department's primary standard.

Quality control in the General Radio Standardizing Laboratory is the result of years of experience in instrument manufacture; it is the customer's assurance of uniformly accurate and reliable instruments for his own testing department.

GENERAL RADIO COMPANY · Cambridge, Massachusetts
NEW YORK LOS ANGELES

OHMITE
Rheostats
For Control of Welding Apparatus
For Control of Instruments and Test Apparatus
For Remote Position Indication
For Control of Lamp Dimming
For Control of Electronic Tubes
For Control of Current and Voltage
For Control of Motor Speed and Generator Fields

Widest Range of Sizes for Every Rheostat Need

Today's critical service requirements further emphasize the basically sound design of Ohmite Rheostats. The all-porcelain vitreous enameled construction and other time-proved Ohmite features provide *permanent* smooth, close control in countless applications . . . control of motor speed and generator fields, of electronic tubes, instruments and test equipment, of welding apparatus, lamp dimming, remote position indication, and many other devices.

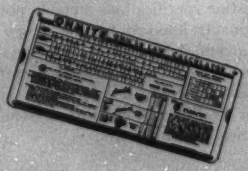
The Ohmite series of power rheostats is the most extensive today, so complete as to make it easy to select the best size for every need. There are ten sizes ranging from 25 to 1000 watts—from 1⅛" diameter to 12" diameter—in straight or tapered winding—in single or tandem units—in regular or special designs—to provide the exact unit for each application. Many stock types. Units produced to Government specifications.

Ohmite Engineers are glad to work with you on any problem to facilitate the design of new devices for today—and *tomorrow*. Write on company letterhead for Catalog and Engineering Manual No. 40.

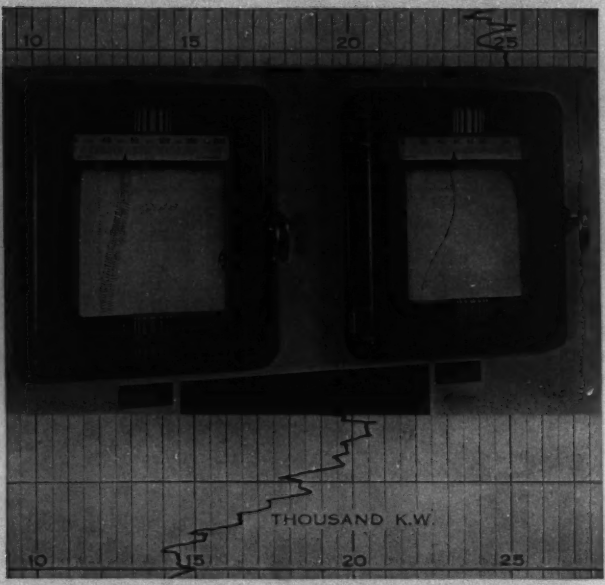
BE RIGHT WITH OHMITE RHEOSTATS · RESISTORS · TAP SWITCHES

Send for Handy Ohmite Ohm's Law Calculator

Thousands of these Ohmite Calculators are in practical use today. Figures ohms, watts, volts, amperes—quickly, easily. Solves any Ohm's Law problem with one setting of the slide. All values are direct reading. Send only 10c in coin to cover handling and mailing. (Also available in quantities.)



OHMITE MANUFACTURING COMPANY, 4833 Flournoy Street, Chicago, Ill., U. S. A.



When load begins to rise, as shown by this Micromax load record, the temperature recorders shown in the insert help watch over generator temperatures. Multiple-point Micromax at left records stator temperatures; single-point instrument at right records rotor temperature.

WHEN OVERLOAD PILES UP

Micromax Temperature Recorders Help Operators

Today, when the burden of carrying maximum load requires power plants to take advantage of every factor at their disposal, Micromax Temperature Recorders are helping to solve several operating problems. Temperature—the condition which determines ultimate load—is used by the operators to show them the net effect of the load changes which are also indicated by ammeters, voltmeters and other instruments.

The operator, guided by these readings, can push overload right up to the highest safe temperature without risk to insulation. When generators are cut in, the danger of loading too rapidly is minimized; nor need the operator waste precious minutes to be safe. He sees the exact temperature increase of rotor and stator on the Micromax record as he increases load. When a generator is taken off the line and must be cooled slowly, he can watch the rate of cooling so that copper and insulation may contract without excessive strain.

Equipping the Micromax instrument to sound an alarm as soon as any temperature reaches a predetermined maximum, leaves the operator free for other duties yet insures his attention the minute it's needed.

Rotor temperature recorders are single-point instruments. For recording stator temperatures, however, 8-point Micromax instruments are used, allowing two measurements for air or hydrogen and six for stator coils.

For further details, we'll be glad to send Catalog N-33-161 *Micromax Temperature Instruments for Electric Power Equipment* on request.

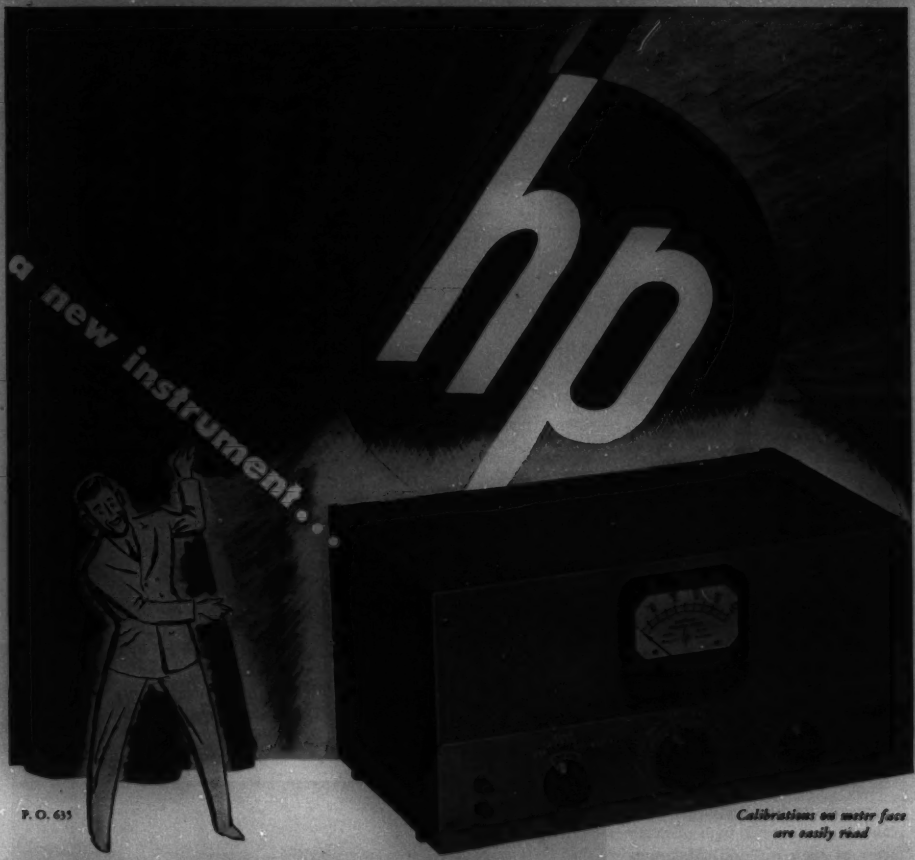
On this control panel for a large hydro station are Micromax temperature recorders for fields and stators of three generators. Shown also are Micromax transformer temperature recorders, and instruments for load-frequency control.

LEEDS & NORTHRUP COMPANY, 4962 STENTON AVE., PHILA., PA.

LEEDS & NORTHRUP

MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS · HEAT-TREATING FURNACES

Jrl Ad N-33-161(3a)



MODEL 500A ELECTRONIC FREQUENCY METER

Model 500A is a direct reading Electronic Frequency Meter to read the frequencies in the range between 10cps and 50kc. At the higher frequencies you can measure the frequency difference between two radio frequency signals. In crystal grinding you can quickly measure the deviation from standard. As with all -*hp*- instruments, simplicity and speed of operation plus high accuracy are prime virtues. Excellent accuracy; plus or minus 2% of the full scale value: Good sensitivity; variation of the input voltage from 0.5 volts to 200 volts will affect the meter by not more than plus or minus 1%. Readings are independent of line voltage since a variation from 105 volts to 125 volts will affect the meter by not more than plus or minus 1%.

Get full particulars about this new -*hp*- instrument today. Data sheets will be sent you promptly and without obligation. Ask, also, for your copy of the new -*hp*- catalog which gives full information about other -*hp*- instruments and explains many standard tests and measurements.

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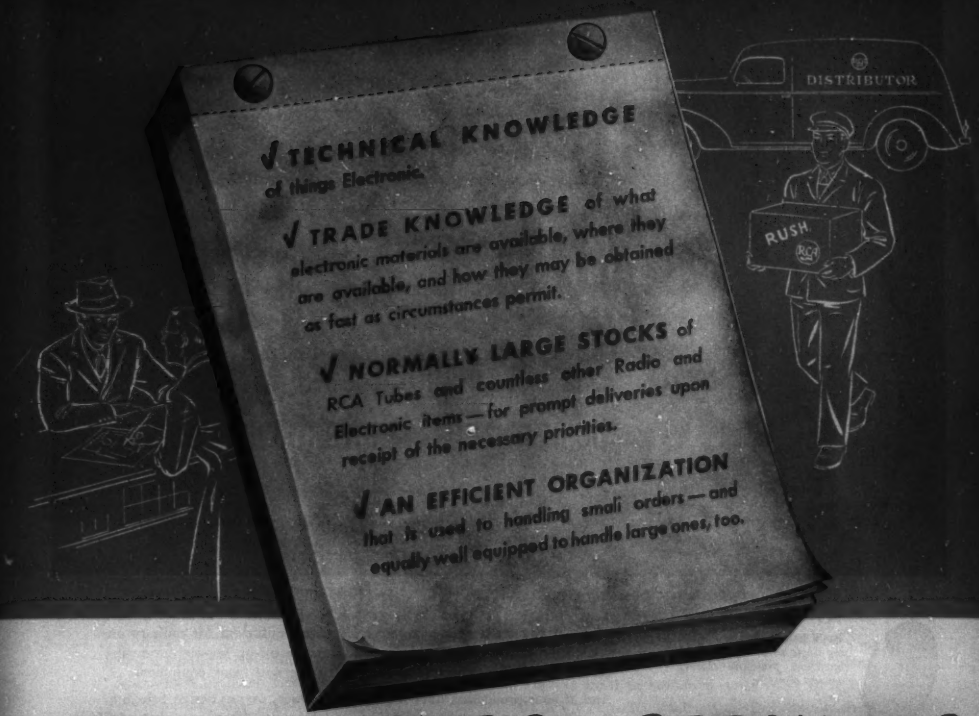
BUY U. S. WAR BONDS AND STAMPS

Your local *RCA TUBE and EQUIPMENT DISTRIBUTOR*


✓ TECHNICAL KNOWLEDGE of things Electronic.
✓ TRADE KNOWLEDGE of what electronic materials are available, where they are available, and how they may be obtained as fast as circumstances permit.
✓ NORMALLY LARGE STOCKS of RCA Tubes and countless other Radio and Electronic items—for prompt deliveries upon receipt of the necessary priorities.
✓ AN EFFICIENT ORGANIZATION that is used to handling small orders—and equally well equipped to handle large ones, too.
DISTRIBUTOR
RUSH

offers You *THESE SERVICES*

'Round the corner from your plant is a man whose chief stock in trade these days is his ability to help busy war industries get needed Radio and Electronic materials faster and use them to better advantage.

That man is your local RCA Tube and Equipment Distributor. Behind him is an organization which has been dealing with things Electronic since the "knee pants" days of Radio.

They know how to get the materials you need. They know how to use these properly once they've been obtained. You'll find their technical advice and recommendations as big a help as their personalized expediting service which assures fast, accurate deliveries.

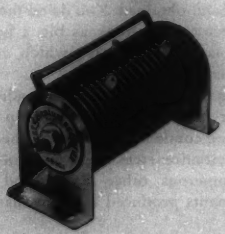
Whether it's one RCA Tube or a hundred—they're ready and geared to help you. They'll help you, too, in obtaining condensers, resistors, rheostats, controls, potentiometers, coils, transformers, wire, and numerous other Radio and Electronic components produced by many manufacturers.

RCA RADIO-ELECTRONIC TUBES

RCA Victor Division, RADIO CORPORATION OF AMERICA, Camden, N. J.

Special Assembly Method — *showing single metal washer which facilitates protective coating against corrosion*

Standard Assembly Method — *showing conventional petal-shaped brass contact washer*



Now – if you are a manufacturer of electrical equipment for military use – we offer you a complete design and manufacturing service, producing Selenium Rectifier power supply units for use with your equipment.

And, if your production lines require D.C. power, we can design Selenium Rectifiers for any power range. Units available with either the widely used standard assembly or the new special assembly, coated for protection against marine and other high humidity services.

All equipment powered by long-life, trouble-free I. T. & T. Selenium Rectifiers – accepted as standard by the electrical industry.

Consulting Engineering Service available. For descriptive bulletins address Technical Department.

SELENIUM RECTIFIER DIVISION

Federal Telephone and Radio Corporation

AN IT&T ASSOCIATE

1000 Passaic Ave.
East Newark, New Jersey

BOEING STRATOLINER

Constant voltage protection all the way

Ask the men who produce planes and the men who pilot them. They'll tell you what vital part *constant voltage* plays in modern aviation. In the sky, it's *constant voltage* on the directional beam which guides the ships through night and storm. In the shop, it's *constant voltage* on the production line which maintains the split-hair accuracy of precision airplane parts.

For the aircraft industry—*and for your own*—SOLA CONSTANT VOLTAGE TRANSFORMERS provide this all-important stabilized power. They stand between costly equipment and destructive voltage fluctuations now common on overloaded power lines. Without supervision they instantly absorb power sags and surges as great as 30%.

For unerring operation of precision tools, and protection of almost irreplaceable instruments and electronic tubes, put SOLA CONSTANT VOLTAGE TRANSFORMERS on duty in your plant. They're built in standard units from 10 VA to 15 KVA capacity—self-protecting against short circuit and without moving parts. Special units can be built to specification.

Note to Industrial Executives: *Find out how Sola "CV" transformers can solve voltage control problems in your operations. Send for bulletin ACV-74.*

SOLA

Constant Voltage Transformers

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago, Ill.

HOW TO SAVE UP TO 47% ON ELECTRICAL COIL FORMS!

HERE'S ALL YOU DO TO MAKE ROCK BOTTOM SAVINGS

READ THIS QUICK CHECK LIST THEN MAIL COUPON FOR COMPLETE STORY!

YOU ENJOY LOWEST PRICES WHEN YOUR COIL FORMS COME WITHIN THESE STANDARDS

*1. **OUTSIDE DIAMETERS** between 1 inch and 3 inches.

*2. **WALL THICKNESSES** between 5/32 inch and 9/32 inch.

*3. **LENGTHS** up to 9 inches (with better prices for shorter lengths).

4. **MAXIMUM** of 20 holes for coil forms ¼ inch and 9/32 inch thick with maximum of 4 holes tapped.

5. **MAXIMUM** of 10 holes for coil forms 5/32 inch to 7/32 inch thick with maximum of 2 holes tapped.

6. **MAXIMUM** of 14 grooves to the inch.

*7. **TOLERANCES** on general dimensions ± 2.0%, but not less than ± 0.010 inches.

Proposed A.S.A. Standards.

In addition to low-cost standard types, Corning Multiform Insulators may be had in almost any other size or shape.

CLIP THIS COUPON TO YOUR BLUE PRINT - MAIL TODAY FOR ACCURATE QUOTATION!

Corning Glass Works
Insulation Division, Dept. N-67, Corning, N. Y.

Please send us estimate on coil forms as per attached blueprint and data below:

Quantity.....

When Needed (date).....

Electrical Characteristics.....

.....

Acceptable Revisions.....

.....

Name.....

Company.....

Street.....

City.....State.....

Pyrex Insulators

"PYREX" is a registered trade-mark and indicates manufacture by Corning Glass Works.

CONTROL CENTERS

Fabricated by KIRK & BLUM

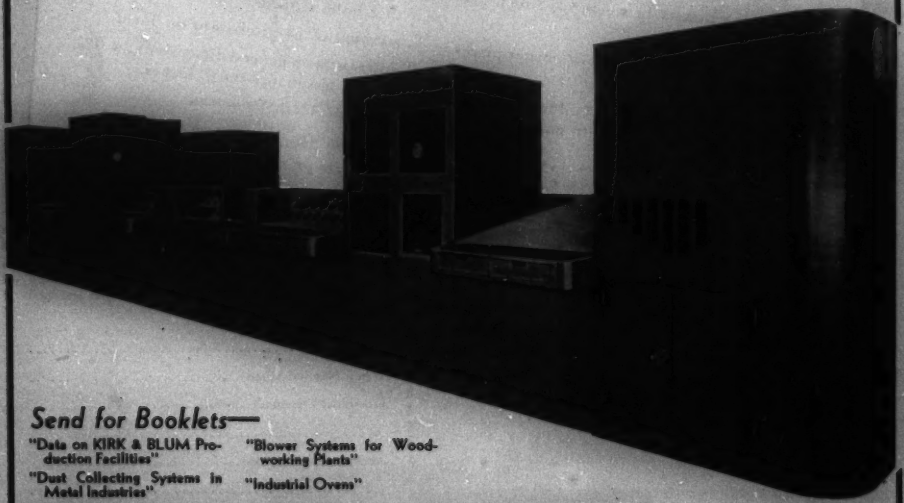
The illustration below is a series of control panels and desks for an airplane motor test room. This entire assembly is an excellent example of one of the various sheet metal products fabricated by Kirk & Blum in strict adherence to customer's design and specifications.

With a background of specialized experience of more than thirty-six years, fabricating sheet metal products for various industries, we can, with equal skill and dexterity, fabricate your special products. Our extensive modern plant facilities and a corps of skilled workmen are further assurance that your work will be completed with speed and economy.

Consult Kirk & Blum Engineers. They will analyze your problems and make recommendations to solve them to your decided advantage.

ACCURATE SHEET STEEL FABRICATION—CAPACITY 3/8 INCH and LIGHTER

SEND US YOUR BLUE PRINTS for PROMPT QUOTATIONS



Send for Booklets—

"Data on KIRK & BLUM Production Facilities"
"Dust Collecting Systems in Metal Industries"
"Fan Systems for Various Industries"
"Blower Systems for Woodworking Plants"
"Industrial Ovens"
"Cooling Systems for the Glass Industry"

THE KIRK & BLUM MANUFACTURING CO.
AN ORGANIZATION OF ENGINEERS AND MECHANICS
2855 SPRING GROVE AVE. CINCINNATI, OHIO

This little drop with billions of others, taken collectively, forms the impervious film which protects the giant transformers, generators and motors of American industry as well as the special electrical units required by our Armed Forces. Such is insulating varnish—although only a few mils thick, it provides the necessary protection to electrical units.

Perhaps you do not know just what type of varnish to specify for treatment of your newly designed units. It is a very complex problem as varnish insulation and treatment which may prove very successful for one type of an electrical unit may be entirely unsatisfactory for another.

We maintain a fully equipped laboratory for those who are confronted with an insulating varnish problem. We are confident, no matter what your problem may be, that with our years of research and specialization in the field of insulating varnishes, we can help you. There are no obligations, so why not let us assist you?

MANUFACTURERS OF

CHINALAK Insulating Varnishes
SYNTHITE Insulating Varnishes
Stator Compounds
Filling Compounds
Cable Enamels
Radio Waxes
Melting Compounds
Sticking Compounds
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Dolphs

JOHN C. DOLPH COMPANY

Insulating Varnish Specialists

166-8 EMMETT ST. NEWARK N J

VARNISHED CAMBRIC • RUBBER POWER CABLES • BUILDING WIRE • RADIO WIRES • SIGNAL CABLE • FLEXIBLE CORDS • LEAD-ENCASED AND PARKWAY CABLES • ARMORED CABLE

CRESFLEX NON-METALLIC SHEATHED CABLE • SERVICE ENTRANCE CABLE • MAGNET WIRE • BARE WIRE

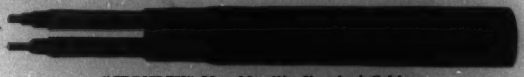
Some of The

CRESCENT

ELECTRICAL WIRES AND CABLES

That Are Meeting Today's Special Needs

For war housing, industrial wiring and interior wiring of all kinds.



"CRESFLEX" Non-Metallic Sheathed Cable

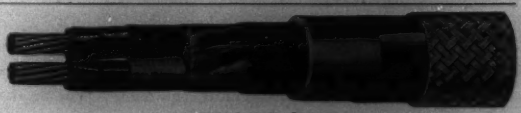
Extensively used in shipyards, and for the manufacture of tanks, guns and planes.

"L" Welding Cable

For portable power leads to drills, tools, welding and construction machinery.

"PERMACORD" Heavy Duty Portable Cable

For electric power and control circuits aboard ship.



SHIPBOARD CABLE

For general industrial power wiring. Widely used because no rubber required in construction, and can carry larger currents for same size copper conductors.

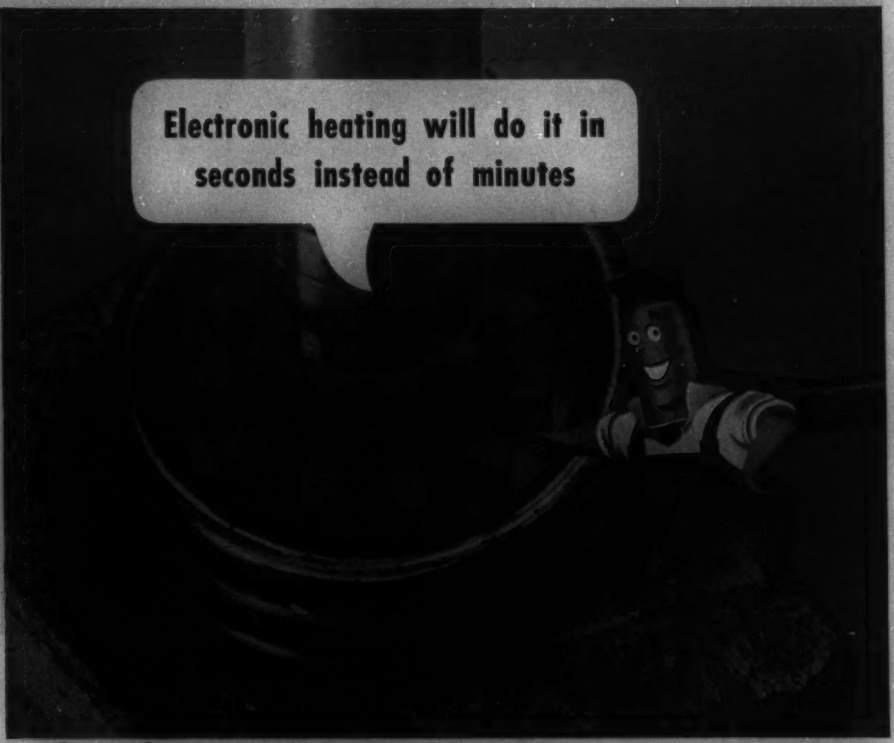
Varnished Cambric Power Cable

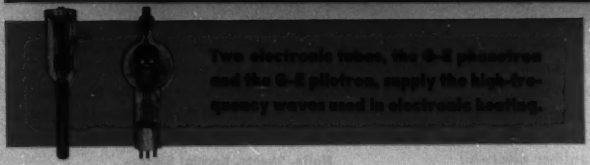
CRESCENT INSULATED WIRE & CABLE CO.

CRESCENT WIRE and CABLE

Factory: TRENTON, N. J. — Stocks in Principal Cities

CRESCENT ENDURITE SUPER-AGING INSULATION • WEATHER-PROOF WIRE





Two electronic tubes, the G-E phanotron and the G-E pliotron, supply the high-frequency waves used in electronic heating.

BY ELECTRONIC heating, small gears can now be case-hardened to a predetermined depth in a few seconds. The hardness pattern may be rigidly controlled as to shape and size. The whole rim of teeth, the tooth tips or the tips and sides of the teeth may be hardened as desired.

In other electronic heating applications, a metal rod is brazed to its metal bushings and terminals in 11 seconds . . . in another, a metal shell is soldered to its base in 3 seconds . . . and in a third case, a glass tube is fused to a metal base in air-tight, permanent bond in 20 seconds. Scores of new wartime uses are showing the advantages of uninterrupted operation, high speed, and quality production.

G-E electronic tubes have two functions in electronic heating. The G-E phanotron supplies the direct current. The G-E pliotron converts this current to high-frequency waves and creates the heating field.

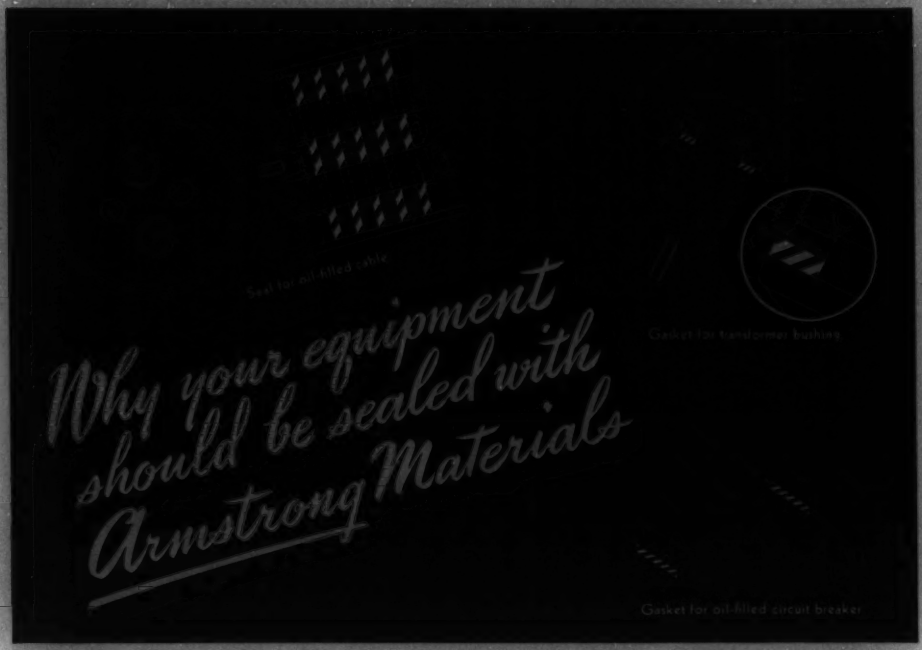
This field may be localized . . . precisely controlled as to amount, direction, or area limit. Few heating methods offer industry such flexibility, accuracy and uniform results.

It is the purpose of the G-E electronic tube engineers to aid any manufacturer of electronic devices in the application of tubes. General Electric, through its nation-wide distribution system, is also prepared to supply users of electronic devices with replacement tubes.

Also, we will be glad to place interested men in your plant on our mailing list. For example, we will send a full-color spectrum chart showing electronic tubes and applications. Write on company letterhead. *Electronics Dept., General Electric, Schenectady, New York.*

On Sunday evening listen to the General Electric Mazda Lamp program over the N. B. C. network. See newspapers for time and station.

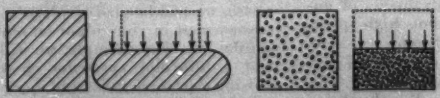
GENERAL ELECTRIC



FOR years, electrical equipment manufacturers have relied upon the Armstrong Cork Company for solutions to their sealing problems.

Armstrong makes more than 50 sealing materials, including synthetic rubbers, cork-and-synthetic-rubber compositions, and cork-and-rubber compositions. Armstrong's sealing specialists know how to determine the *right* material for any sealing job.

For example, you may need a tough, resilient, oil-resistant, weatherproof gasket that will compress without side flow. Synthetic rubber meets all these requirements except one: it flows under pressure. Cork, on the other hand, is truly compressible.



It does not flow laterally, but changes its shape only in the direction of the applied force. Armstrong combines cork and synthetic rubber to produce compositions which provide cork's compressibility plus synthetic rubber's mechanical strength; resistance to oils, solvents, sunlight, corona; and imperviousness to liquids and gases.

For services where there is no need for true compressibility, or where lateral flow is desired, Armstrong makes materials that contain no cork.

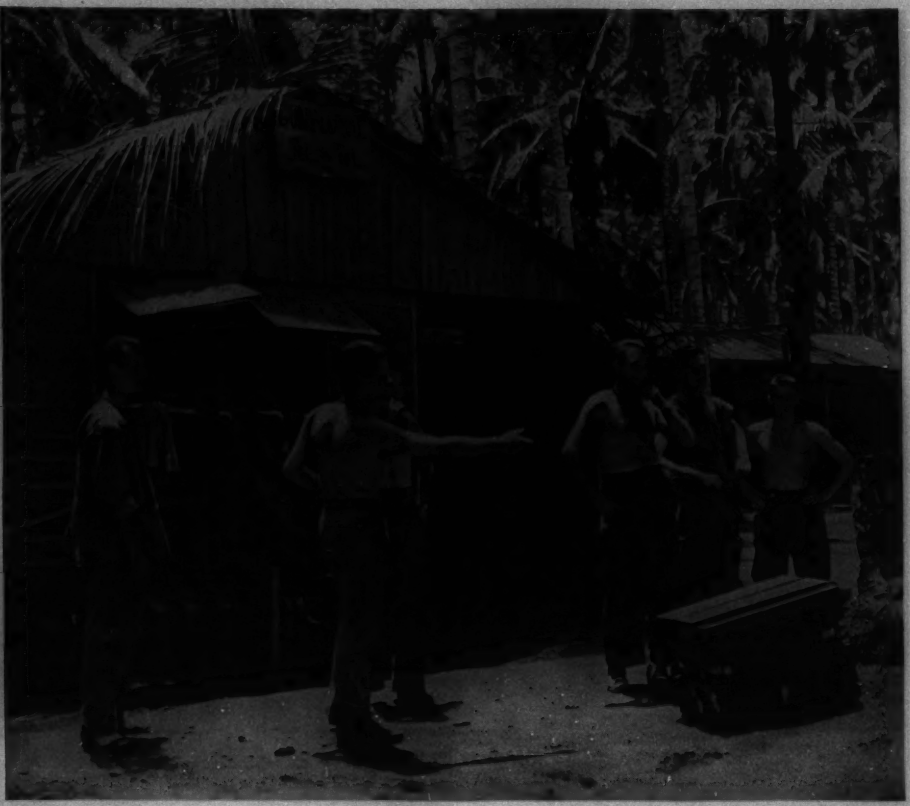
Rolls, Sheets, Special Shapes

Armstrong Compositions are available in rolls, sheets, gaskets, and molded or extruded shapes—for sealing transformers, switches, potheads, oil-filled cables, circuit breakers, condensers, and other electrical equipment. For practical, unbiased recommendations, send your sealing problems to Armstrong Cork Company, Industrial Division, 4006 Arch Street, Lancaster, Pa.

ARMSTRONG'S GASKETS • SEALS • PACKINGS

Synthetic Rubbers • Cork-and-Synthetic-Rubber Compositions • Cork-and-Rubber Compositions
Cork Compositions • Fiber Sheet Packings • Rag Felt Papers • Natural Cork

"FORMERLY 'CORPRENE'"



"Just getting the wire laid was a tough problem. Keeping it intact in bombings, shellings and adverse weather is a twenty-four-hour proposition. . . . Wire repair crews are made up of four men. Three stand guard while the other works."
(From story by Sgt. James W. Hurlbut, Marine Corps Combat Correspondent)

Telephone Exchange on Guadalcanal

Marine communications men built it under fire. And it has been kept built. The "Guadalcanal Tel & Tel" covers well over a thousand miles of wire.

That is where some of your telephone material went. It's fighting on other fronts, too. We're getting along with less here so they can have more over there.

Telephone lines are life-lines and production lines in a war. Thanks for helping to keep the Long Distance wires open for vital calls to war-busy centers.

WAR CALLS COME FIRST

BELL TELEPHONE SYSTEM

1230 SIXTH AVENUE • ROCKEFELLER CENTER • NEW YORK

UNITED STATES

1 TRUCK FOR U.S. Laytex ASSAULT WIRE

REG. U. S. PAT. OFF.

4 TRUCKS RELEASED FOR OTHER MATÉRIEL TRANSPORT

Every day our Armed Forces are in the field, distances from base to front lengthen... problems of transportation increase... every cubic foot of space that can be saved for the S.O.S. is vital.

U. S. Laytex Assault Wire requires only 1/5 *the space in transport of ordinary communications wire.*

In the unique Laytex Process, the compounded, purified latex is applied to the electrical conductor by dipping. Conductors are perfectly centered and the weight of the insulation and the diameter of the insulated conductor are kept at the minimum.

Lightweight and small bulk are only two advantages of U. S. Laytex Assault Wire. It resists concussion and a wide range of temperature changes. Laytex is waterproof and extremely flexible.

Laytex Assault Wire weighs less than 30 lbs. per mile... a mighty important feature when men are marching with full equipment. It has a talking distance of five miles and a breaking strength of 50 lbs. per conductor.

UNITED STATES RUBBER COMPANY

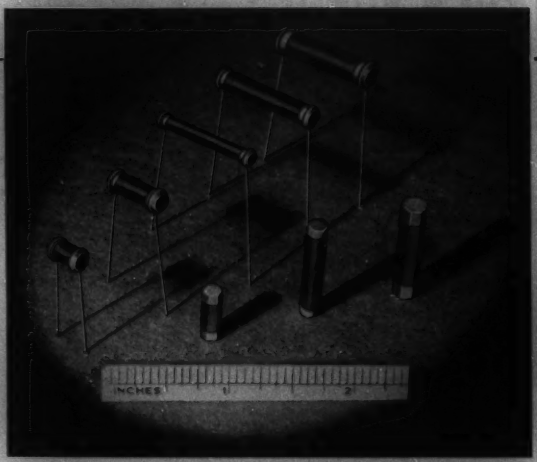
RUBBER COMPANY

KEYSTONE'S *New Development*

NEGATIVE TEMPERATURE COEFFICIENT RESISTANCE MATERIAL . . .

DEVELOPED to compensate for electrical resistance changes due to temperature variations—to reduce or eliminate initial current surge in electrical equipment—to provide various degrees of time delay in electrical units—used as a remote unit for temperature measurement, etc. . . .

Write for information.

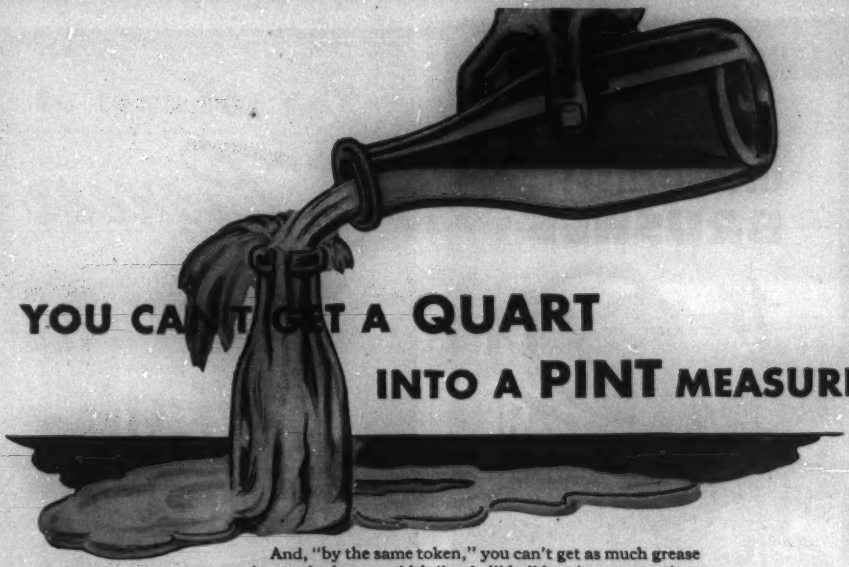


Representative units

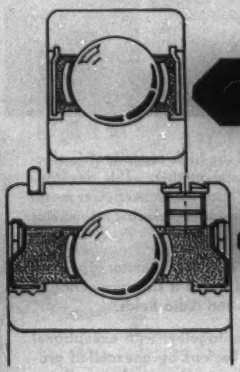
Manufactured by

KEYSTONE CARBON COMPANY, INC.

SAINT MARYS . . . PENNA.



YOU CAN'T GET A QUART INTO A PINT MEASURE



And, "by the same token," you can't get as much grease into a single-row-width "sealed" ball bearing, as goes into the double-row-width "CARTRIDGE" BALL BEARING of equal bore and outside diameter. Look at the section drawings herewith, and you'll see why.

[redacted]-width shielded or "sealed" bearing, [redacted] grease space inside the sealing plates. [redacted] here is no space available for a highly- [redacted]e-tight seal.

Now, in contrast, see that big grease reservoir between the seals, in the "CARTRIDGE" BEARING section—providing at least DOUBLE THE GREASE CAPACITY of the shielded or "sealed" bearing, and greatly extending the [redacted] Note, too, how the wide, inwardly-ex- [redacted] and the oil grooves on the inner ring, [redacted] AN IDEAL SEAL THAT PREVENTS THE ESCAPE [redacted] AND EXCLUDES DIRT, whatever the shaft angle.

Furthermore, the "CARTRIDGE" SEALS ARE REMOVABLE AND REPLACEABLE, should you wish to inspect the bearing or change the grease. And the refilling plug makes it easy to put in a new charge of grease. You can't do this, with the ordinary shielded or "sealed" bearing, which is permanently sealed.

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Summing up . . . all these distinctive features of the NORMA-HOFFMANN "CARTRIDGE" [redacted] mean prolonged bearing life, less lubrication attention and lower maintenance cost. Write [redacted] the Catalog enumerating many additional advantag[redacted] Let our [redacted] neers work with you.

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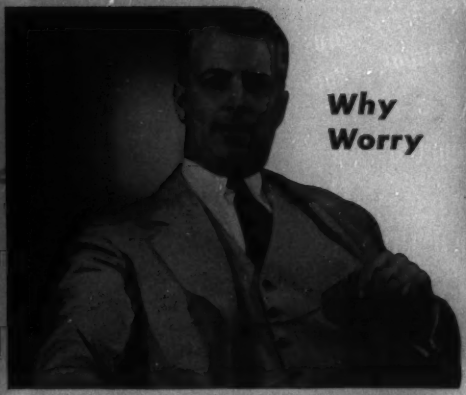

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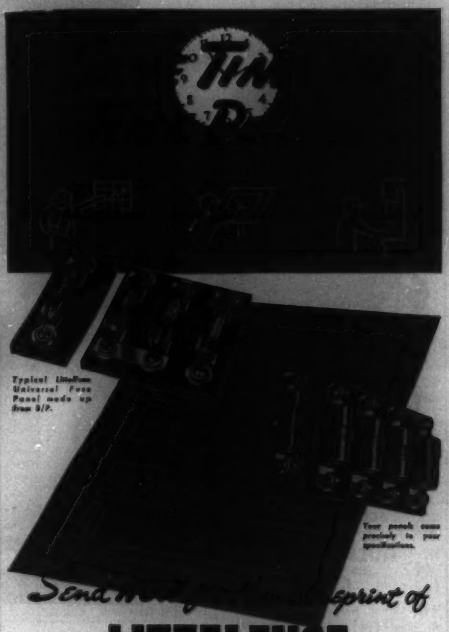

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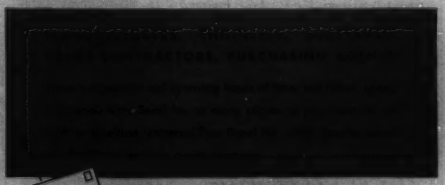

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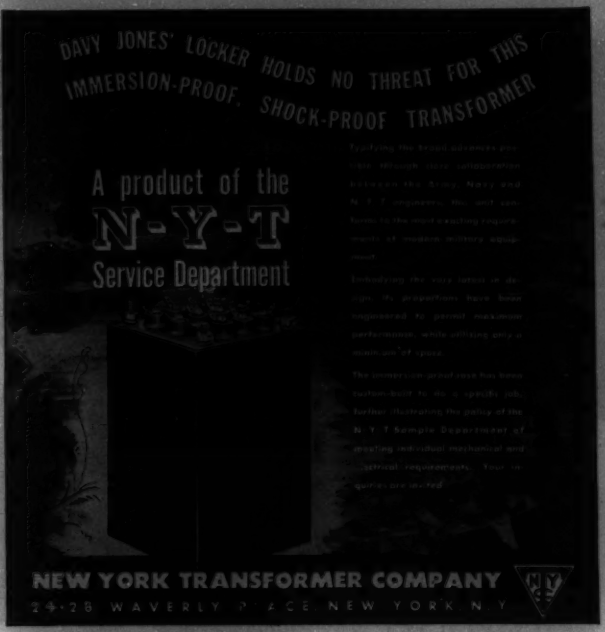
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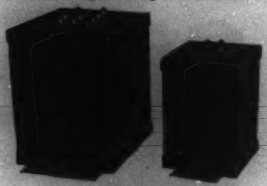

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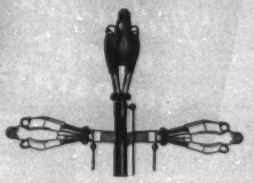

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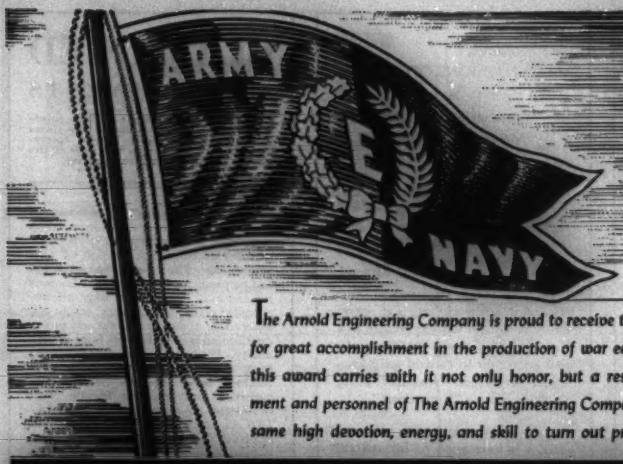

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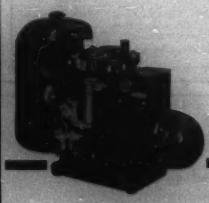

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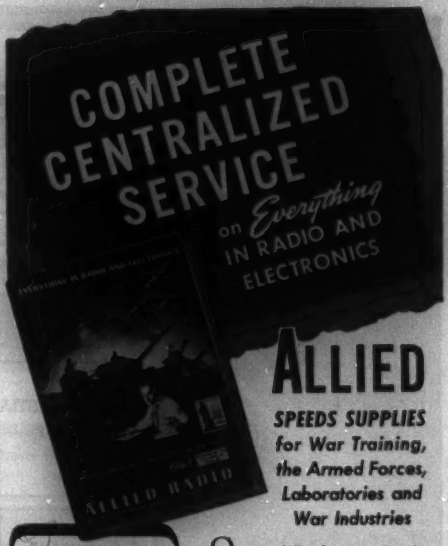

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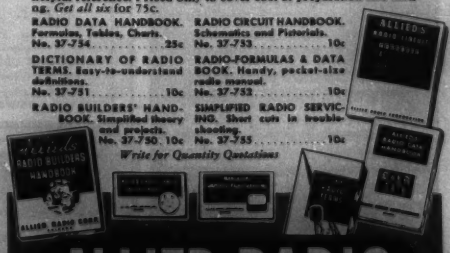

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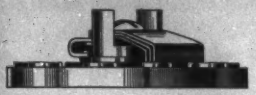

This is the shorting type. As the arm is rotated from one position to another the adjacent contact points are "shorted" (bridged).

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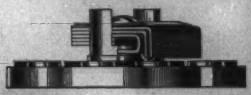

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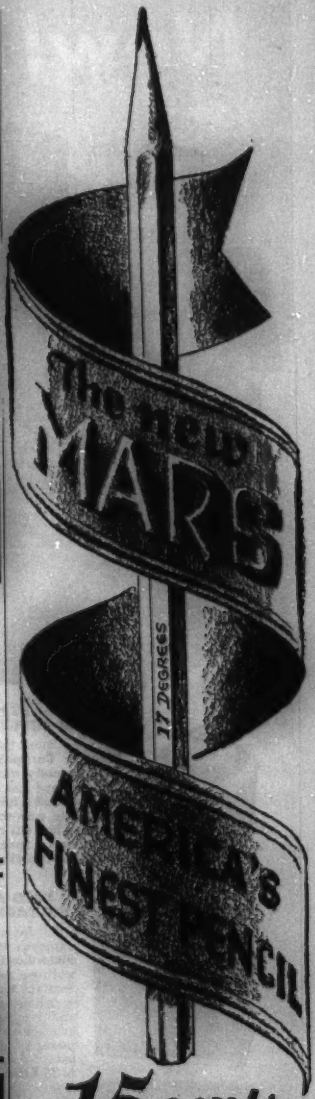

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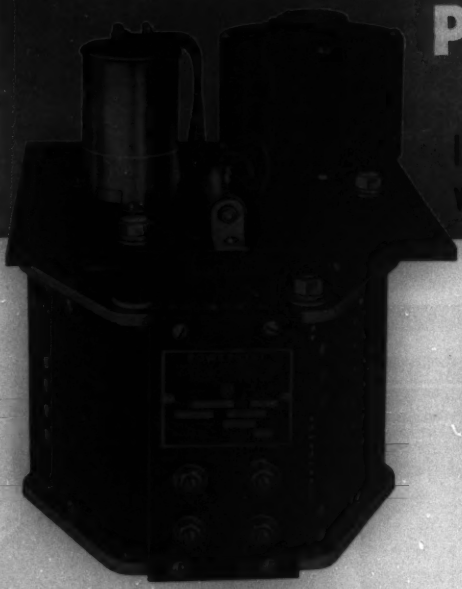

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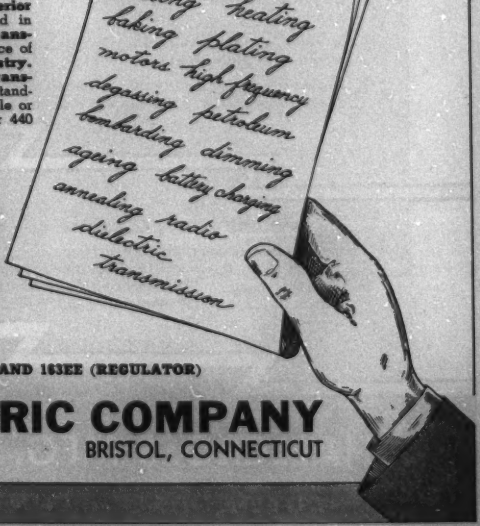

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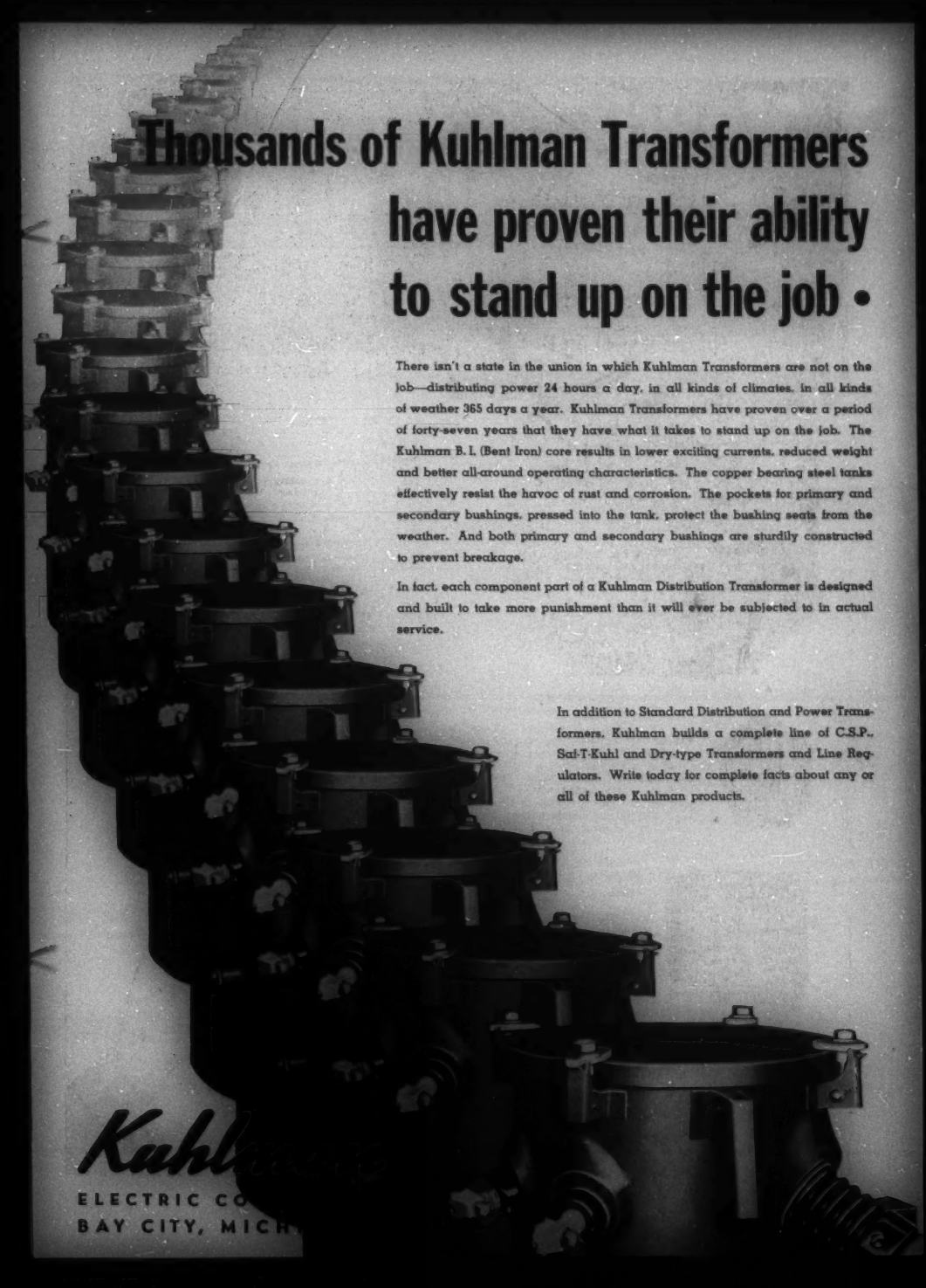

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